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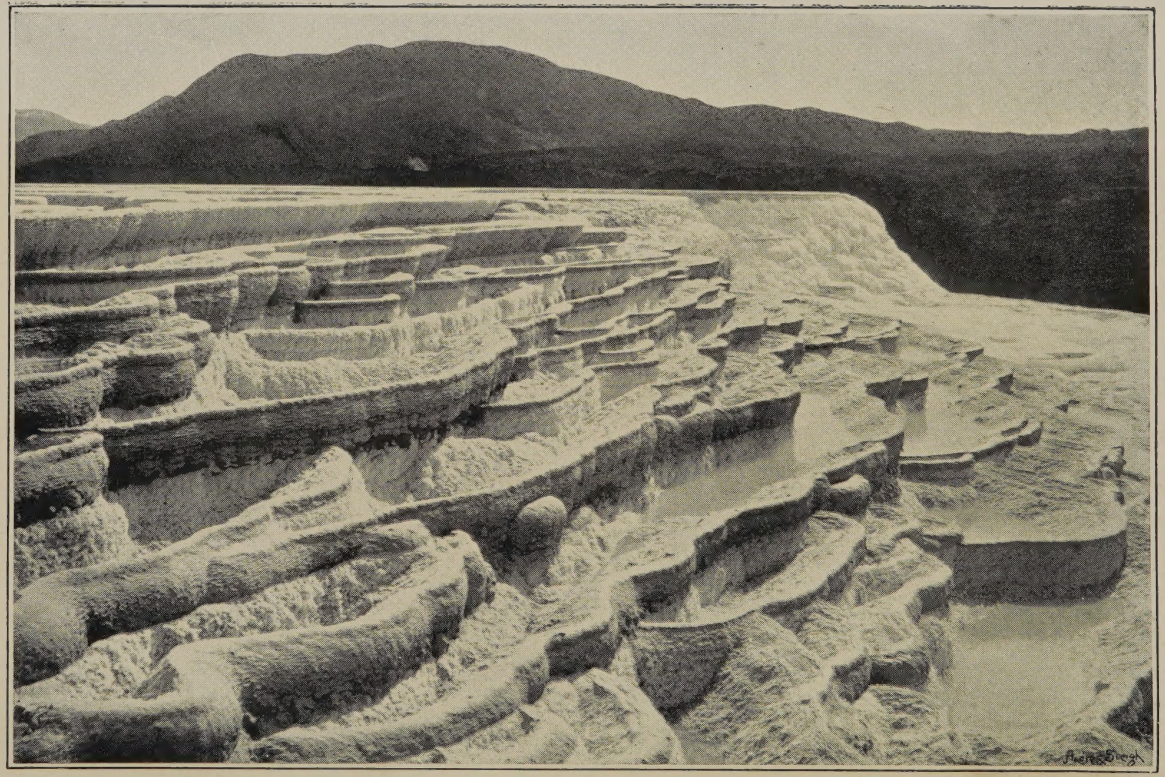

FIG. 59.—Silica Terraces at Rotomahana.

Hot water, emerging from the earth and containing much dissolved silica, poured down over a series of terraces into the lake below. The waters, depositing their silica on contact with the air, gradually built up a wonderful series of snow-white silica terraces at Rotomahana, which was once termed the "eighth wonder of the world." The whole fairy scene has now been destroyed by volcanic action. (*See page 278.*)

(From a Photograph by Messrs. Burton Bros., Dunedin.)

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TRIUMPHS & WONDERS
OF
MODERN CHEMISTRY

A Popular Treatise on Modern Chemistry and its Marvels, written in Non-Technical Language for General Readers and Students

BY

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Dedication

TO

MY DEAR MOTHER

THIS BOOK IS DEDICATED

PREFACE

WITHIN the last few years Chemistry has been revolutionised by startling discoveries which have followed one another in quick succession, and these are briefly described in the following pages. The atoms have been shown to be of immense complexity, the seat of vast forces and terrific motions, the very existence of which was scarce dreamt of until the advent of radium. A series of magnificent researches has recently shown us that these atoms, far from being the changeless and eternal foundation stones of the Universe that they were once thought to be, are themselves crumbling away. Such conceptions and discoveries have altered the whole aspect of chemistry, and have necessitated the treating afresh of many old problems previously regarded as settled.

It has been my lot while lecturing on Chemistry to have come into frequent contact with many thoughtful men and women, boys and girls, who have felt much interest in this new chemistry, which has arisen out of the old, and who have wished to know something more of the grand questions of the day touching the ultimate nature and constitution of the Universe in which they live, and of the matter which surrounds them on every side in untold millions of tons, but who have neither the leisure nor the inclination to master the technicalities and enter into the minutiæ of the regular text books of Chemistry where such things are discussed. These text-books, moreover, labour under the disadvantage that they are written for candidates studying for one or other of the innumerable examinations in which our University authorities take such a keen delight, and which, combined with a complete lack of educational freedom, make an English University Student's life a perfect nightmare to him (in sad contrast to that of a German or American Student),

and destroy rapidly and effectively any genuine interest in Science that he may have possessed at his entrance to the University, besides exercising a paralysing effect on the University Lecturers themselves, and diminishing greatly the output of research work in this country, to its incalculable material and moral harm.

This book is not written for examination candidates. It is written in order to awaken the interest of the general reader and the young student in what is after all a *grand* science; for Chemistry is the Science which tells us that Nature works by unseen bodies—by myriads of tiny atoms whirling in gigantically swift and infinitely complex motion, the whole forming a microcosmic world beneath the visible world—and that her true laboratory consists of "events in inconceivable numbers, the whole phantasmagoria of these events changing every instant down to its minutest details with inconceivable rapidity." The most insignificant objects are fraught with endless wonder and mystery. A breath of wind is the swift rush of millions of atoms, the blazing of a match the destruction of a universe almost infinite in com plexity and the building up of a new one out of its ruins, while in the tiniest grain of dust dancing in a sunbeam the rush of atomic events in the millionth part of a second is so incredibly swift as to defy all conception and calculation. Indeed, the whole universe, from its uttermost heights to its deepest depths, is but one vast system in a state of ceaseless and stupendous chemical change. This book represents an effort to give the general reader a picture of the world in which the chemist wanders, and an idea of the great and wonderful problems with which modern chemistry deals. At the same time it is hoped that the book will prove useful both to *popular lecturers* and to *Chemistry teachers* in need of interesting illustrative facts for their routine chemical classes.

Every care has been taken to keep the subject matter as thoroughly up-to-date as possible. In every case the most recent authorities, not only English but foreign as well, have been consulted, and references are given to much of the original literature for those who wish to pursue the subject further. No one authority has been slavishly followed, but

an endeavour has been made to put every fact in a fresh and original way. Indeed, the reader will find several new views published here for the first time, while many old problems have been presented in a novel form and treated on lines different from those usually adopted in the ordinary chemical text-book. Part of my object has been to break away from the stereotyped text-book style, without thereby sacrificing scientific exactitude and precision. By such means I hope to bring the reader into immediate contact with the thoughts of the great leaders of science, whose ideas, usually buried away in the transactions of learned societies, are inaccessible to all but the specialist.

My searchings in the original memoirs and addresses of the great leaders of chemical thought have been very extensive, and represent a labour extending over some years. If, however, I succeed in awakening the interest of the intelligent reader in our science, such labour will not have been in vain.

On every doubtful point I have not hesitated to consult with leading authorities who have made a special study of the subject, and so I hope that few errors will have crept into the following pages, and that the views presented will be in accordance with the most recent results of scientific research.

My best thanks are due to Dr. Henry J. S. Sand, Ph.D., D.Sc., whose deep and exhaustive knowledge of the most difficult developments of Modern Chemical Science was ungrudgingly placed at my disposal in writing this book. Almost every page has been benefited by his criticism and advice.

I am much indebted to Sir William Crookes, F.R.S., for his kindness in revising the chapter on Nitrogen and our Food Supply, to which he appended some observations and corrections, which are all the more valuable since they come from the eminent chemist who first called the attention of the scientific world to this great problem in his famous address to the British Association.

To Mr. Frederick Soddy, M.A., I am indebted for information and corrections on the radio-active elements—a subject on which his researches have become classical. To Dr. Caven, D.Sc., F.I.C., I am indebted for some manuscript notes, which have enabled me to treat some portions of the

subject in an original manner. Mr. Golding, F.I.C., of the Midland Agricultural College, Kingston, Derby, was kind enough to allow me to reproduce photographs illustrating his experiments on " Nitrogen-fixing " organisms ; I have also to thank him for advice and information on this subject.

My best thanks are due to Mr. Prichard, of the Nottingham Library, for the trouble he took in looking up books and records for certain information ; also to my wife for many suggestions, useful criticism, and active help.

Among other authorities with whom I have had occasion to correspond while preparing this book may be mentioned : Miss Ida Freund, of Girton College, Cambridge, who gave me some information regarding Lucretius' Poem " De Rerum Natura " ; Mr. W. C. D. Whetham, M.A., F.R.S., who gave me leave to use part of his book, " Recent Developments of Physical Science " ; Mr. Edwin W. Streeter, who allowed me to quote from his work on " Precious Stones " ; Mr. J. E. Gore, F.R.S., who revised some of the astronomical statements made in the early parts of the work, and who gave me permission to quote from some of his works on Modern Astronomy ; Mr. Kipling, who gave me leave to quote from his poem " Sea-Cables " ; Sir William Ramsay, F.R.S., who corrected some statements regarding his researches ; Mr. Edw. A. Oates, British Vice-Consul at Porto Empedocle, Sicily, who procured for me illustrations of the Sulphur District, Girgenti, Sicily ; Bryant & May, who gave me information on Match Manufacture ; Siebe, Gorman & Co., who gave me information and illustrations regarding their oxygen apparatus. Among the firms who have allowed me to quote from some of their publications may be mentioned : Kegan Paul, Trench, Trübner & Co. ; The Cambridge University Press ; Macmillan & Co. ; The Proprietors of *Cassier's Magazine ;* Harper Brothers ; Seeley & Co. ; Grant Richards ; Methuen & Co. ; John Murray ; Smith, Elder & Co. ; *The English Illustrated Magazine ; The Strand Magazine ; The Forum.* To all of these I return my best thanks.

GEOFFREY MARTIN.

BIRKBECK COLLEGE,
UNIVERSITY OF LONDON.

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TRIUMPHS AND WONDERS OF MODERN CHEMISTRY

CHAPTER I

THE MYSTERY OF MATTER

THE endless circulation of matter in the universe is, perhaps, one of the most wonderful facts with which chemistry has to deal. It is this endless change which causes the history of the most common and insignificant objects about us to be more astonishing than any fairy tale. What a wonderful story, for example, could be written of the material which forms our bodies! It came into existence in the immense depths of space millions upon millions of years ago, and wandered for ages through darkness and void until it reached our earth. Perhaps it fell upon the earth in a fiery meteorite, or perhaps it merely joined the huge fire mist from which our solid world condensed. Since then it has run round age after age in an endless circle of change. First it formed part of that vast primeval atmosphere which surrounded the globe, and blew in mighty winds around our planet; then it was absorbed into the body of some humble living being, and when this being died and its body decayed, the matter passed into the rich mother earth. Thence it passed into some plant by means of its roots; and from the plant it passed, by the process of being devoured, into the body of some animal; and from the animal again it passed to earth and thence to plants and animals again; and so on through an endless cycle of change, coursing through the bodies of innumerable multitudes of living forms, which stretch far back in a dim unending vista into the depths of time. Finally it reached man; yes, the very atoms which thrill and flash in our brains and muscles

once formed part of a living plant or animal millions of years ago, and will again form part of a living plant or animal millions of years hence. In some form or other the matter which now forms our bodies will exist long after the whole present order of creation has passed away; indeed, it may well yet blow in the winds of worlds as yet unborn, and thrill in forms of life not yet evolved.

This ceaseless round of matter seems to have impressed Shakespeare, who has caused Hamlet, not pleasantly, to refer to the subject more than once. In Act IV. Scene 3, we have the man eating the fish that has fed on a worm, which in its turn was sustained upon a dead emperor, and are shown "how a king may go a progress through the guts of a beggar." In Act V. Scene 1, there is the notable speech of Hamlet, when he says,

> "Alexander died, Alexander was
> buried, Alexander returneth into dust: the
> dust is earth; of earth we make loam: and
> why of that loam, whereto he was converted,
> might they not stop a beer-barrel?
> Imperious Cæsar, dead and turned to clay,
> Might stop a hole to keep the wind away.
> O, that that earth, which kept the world in awe,
> Should patch a wall to expel the winter's flaw!"

Not only the material forming our bodies, but every piece of material around us possesses an antiquity so vast as to be almost incredible. What endless convolutions and vicissitudes, for example, has a common lump of earth passed through before it reached its present form? It has been part of continents which have long since vanished, and has borne the tread of races long since extinct. It has been on the top of mountains and at the bottom of oceans; it has often formed part of the molten fire underground, and, in spite of all this, it still remains, and will remain during endless ages yet to come.

All these wonders arise from the fact, brought to light by the patient labours of generations of scientific men, that matter is indestructible, that it can be neither generated nor destroyed by any means in our power. It may pass

into a totally different series of forms, but at the end of a whole series of changes the same weight of matter remains as was there in the beginning. For example, when a candle burns away it disappears, and the matter forming it is apparently annihilated; yet this is not really so, for the candle merely burned to invisible gaseous forms of matter, which, when collected and weighed, are found to contain the same weight of carbon and hydrogen (the kinds of matter which make up the candle) as was originally in the candle itself. This latter fact, indeed, can be shown easily by means of a very simple experiment. A candle *C* is fixed in a stoppered bottle *A* (Fig. 1), which is then weighed. The candle is now lighted by making a platinum wire *BB*, which encircles the wick, white hot by means of an electric current. The candle burns for a short time, and then goes out. On reweighing the bottle when it is cold, no alteration in weight will be found to have occurred, although part of the candle has burned into invisible gas.

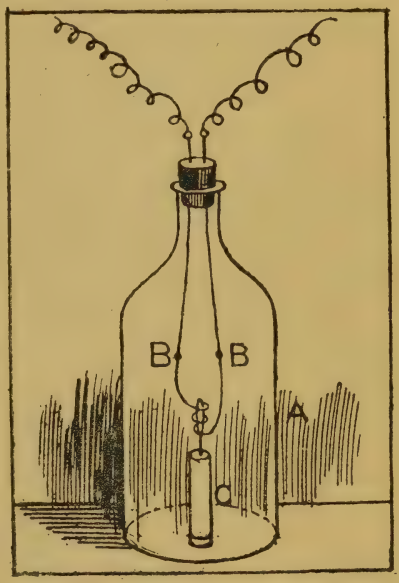


FIG. 1.

In the light of recent discoveries, however, it may be doubted whether matter is absolutely indestructible, but there is no doubt that ordinary matter, if decomposable at all, decomposes so slowly that a single pound of it will endure through millions of millions of centuries, a time longer than that required for the whole solar system to evolve.*

It is indeed hard to conceive that anyone in full possession

* Sir Oliver Lodge, "Modern Views of Matter" (1903), p. 25.

of his senses can look into the heavens on a dark starry night and remain unmoved. The fact that he looks into a vast void extending upwards for ever and ever, strewn with innumerable myriads of suns and world-systems, must fill even the most brutalised mind with a feeling of awe and bewilderment. Yet the interspace between world and world is not truly empty in the popular sense, for it is filled with a wonderful medium, termed the ETHER, which fills all the depths of space, and bears through it to us, in the form of minute ripples or quiverings, the light of the distant stars. Matter moves through this vast sea of ether, apparently without resistance, much as a sieve moves through water, or a wind rushes through the trees; but what "matter" is, we do not know. All that we do know is that it is totally unlike anything which our crude senses conceive it to be, and is probably far more wonderful than anything we can even imagine.

We know that the solid objects about us are not really solid and impenetrable. They consist of countless millions of tiny particles, tiny atoms as chemists call them, in unceasing and swift motion. A single grain of lycopodium powder is made up of over a trillion of such atoms; earth, the paper on which I write, the very air we breathe, consists of unimaginable millions of these tiny worlds, rushing and revolving as rapidly as rifle bullets. Mendeleef likens the atoms to the heavenly bodies, the stars, sun, planets, satellites, and comets, and he considers that the building up of molecules from atoms, and of substances from molecules, resembles the building up of systems, such as the solar system, or of twin stars, from these individual bodies.

Even these atoms which build up ordinary matter are by no means solid masses. Far from it. Each atom is probably composed of a few thousands of tiny specks of negatively electrified particles, which fly about in astronomical orbits inside the atoms (much as a swarm of bees would fly about inside the dome of a great cathedral) forming a kind of cosmic system under their strong mutual forces, and occupying the otherwise empty region of space which we call the atom.

The porosity of matter as thus constituted is extreme, and this explains why it can move through the ether without apparent resistance. Matter hangs in space like a faint cloud, and is perhaps a mere misty modification of the wonderful space-filling fluid. Indeed, there is reason to believe that the one massive constituent of the universe is this invisible ether, and that our matter is a mere gauzy cob-web, a mist, or a milky-way floating in it. The reason why matter appeals to us so strongly and clearly is because our bodies are composed of it, and because our sense organs have been evolved to respond to its various motions.*

"Matter," says Francis Galton,† "is a microcosm of innumerable and, it may be, immaterial motes, and . . . the apparent vacancy of space is a plenum of ether that vibrates throughout like a solid." Nor must we forget that matter, as we know it, is but a collection of sensations generated in our brain by an exciting cause; the matter itself which lies behind and gives rise to these sensations remains for ever unknowable, hidden behind the veil of changing phenomena. It is none the less real for all that, but still the fundamental fact remains that of the outer world we know nothing except our sensations. A landscape is nothing but a cluster of sensations. So also is a beautiful woman, a lovely flower, a child, a book. Between us and external reality stands as an impenetrable intermediary, our nervous system. When we attempt to understand the inmost nature of the outer world we stand before it as before utter darkness. Outside of ourselves there exists in Nature neither sound nor silence, brightness nor darkness, neither colour, odour, space, force, nor anything that we know as sensation. The multitudinous sounds of Nature, the creaking of carts, the cries of animals, the wail of music, the awful roll of thunder, are all produced by the excitement of our acoustic nerves, and exist only in our brains. As to the excitement itself, there is nothing to indicate that it is sonorous. It is in our brain that noise is produced; outside

* Sir Oliver Lodge, "The Structure of the Atom," *Journal of the Society of Chemical Industry* (1908), Vol. 27, p. 731.

† *The Times*, May 31, 1910.

of it reigns eternal silence, or worse, since silence is the correlation of noise. Similarly light is produced by the excitement of the optic nerve, and shines only in our brains ; the ethereal vibrations themselves are not luminous. Outside us, then, is utter darkness ; the flashing lights and colours of the outer world which incessantly assail us, the sudden glare of lightning, the gleam of gold and scarlet, the green of trees and fields, all the visible glories of the outer world, exist but in our brain ! The same is true of all our other senses, and affects to an unknowable degree our conception of matter. We are utterly walled in by our nervous system.

We will now give a brief account of the views of the foremost modern thinkers upon the constitution of matter. A wonderful theory of Professor Osborne Reynolds* assumes that the ultimate particles which make up matter are nothing but empty cracks flitting to and fro like silent ghosts through the vast stagnant sea of ether. The ether is supposed to consist of an arrangement of indefinite extent of uniform spherical grains, generally so close that the grains cannot change their neighbours, although continually in relative motion with each other. The grains are extremely minute, the diameters being 5.534×10^{-18} centimetres (1 inch is 2.5 cms.). The millionth part of an inch could contain half a billion such particles packed side by side. The pressure in the medium is about 10,000 tons per square centimetre. In spaces in which there occur a smaller number of grains than is necessary to render the piling "normal," such local deficiencies are permanent. They can run through the medium without the medium moving with them, much as waves pass over water without a transfer of matter. They attract each other according to the laws of gravitation, and constitute the particles of matter. Hence, in contradistinction to our usual notions, matter consists of merely cracks or gaps in space ; it is "emptiness," and not "fullness," as one would naturally suppose.

* "The Sub-Mechanics of the Universe," Cambridge University Press, 1903.

This theory gives a complete explanation of gravitation, the velocity of light, and numerous other physical phenomena.

According to another theory, matter is an electrical manifestation. It consists in aggregations of electrical particles, called by some authors, "electrons," by others, "corpuscles." The diameter of these particles has been calculated to be only 0.961×10^{-13} centimetres;* so that over 20,000,000 could be packed side by side in the millionth of an inch.

All the different elementary chemical atoms are made up of aggregations of many thousands of these minute bodies; these electrons or corpuscles, therefore, correspond to the long-sought primary matter or "protyle," out of which all the chemical elements are built up.

According to Larmor, the electrons are nothing but centres of strain, probably minute eddies, in the ether. These strain centres must not be thought of as parts of the medium for ever separated from the rest, for it is the strain alone which persists, the part of the ether which is affected by it constantly changing as the sub-atom is moved.

In Whetham's words,† "Matter is a persistent strain form "flitting through a universal sea of ether, and ether, in its "turn, is a close-packed conglomerate of minute grains "in continual oscillation. . . . But what of the grains "of which the ether is composed?

"Are they 'strong in solid singleness' like the one-time "atom of Lucretius? Or have they parts within which "opens a new field of complexity? Of what substance are "they made?

"Has a new ether more subtle than the first to be invoked "to explain their properties, and a third ether to explain "the second? The mind refuses to rest content at any "step of the process. An ultimate explanation of the "simplest fact remains, apparently for ever, unattainable."

* Arrhenius, "Theories of Chemistry" (London), 1907, p. 91.

† "Recent Advances in Physical Science" (1904), pp. 282-294, (Murray).

If matter is but a number of minute whirlpools in a universal sea of ether, surely by the slow diminution of their velocities in the course of ages these whirlpools must ultimately die out, again passing into the ether? The idea of the slow passage of matter into ether has been put forward by many recent writers, amongst whom may be mentioned Le Bon.* According to such a view, the material universe must be slowly disappearing. So that even the stately world-systems of space are smitten with a process of slow decay; even as the planets circle in silence around their central suns, they are rushing into oblivion, and ultimately must vanish, like clouds in a summer's sky, leaving no wrack behind them to show that they have been and gone. We have, however, no experimental proof of this view.

The most fundamental property of matter for dynamical science is *mass*. The mass of a body used to be defined as a measure of the quantity of matter it contained. It is explained by the electronic theory of matter as an effect of electricity in motion. If this is so, it can be shown that the mass of a body must increase with its velocity, and, indeed, actual experiments by Kaufmann showed that this is the case. According to this idea, the mass of a body is not invariable, but rapidly increases as its speed approaches that of light (3×10^{-10} cms. per second, or 186,000 miles per second), and were it actually to attain this speed, its mass would become infinite. It follows, therefore, that the velocity of no material body can exceed that of light. But if the velocity is less than the tenth part of this, the difference in mass from that at very low velocities is insignificant—below one per cent. As a matter of fact (excluding certain Cathode and Beta rays), matter is never observed with such high velocities. Even when planets crash together in space and flash instantly into vast masses of glowing rushing gas heated to a temperature almost inconceivable to us, the flying masses of ejected matter never attain velocities approaching that of light. Thus the eruptions in the new

* "The Evolution of Matter," by Dr. Gustave Le Bon (London), 1907. (Kegan Paul, Trench, Trübner & Co.)

star of Perseus, in 1901, the result of some tremendous cosmical collision, did not attain a velocity greater than 466 miles per second. The greatest observed velocity of the huge flames on the sun is 528 miles a second—a velocity exceeding that of a rifle bullet nearly a thousand times. Tremendous as these velocities seem, they are barely the four-hundredth part of the speed of light, so that the deviation from the law of constancy of mass must, even in these extreme cases, have been insignificant.

The amount of matter in the universe is so great as to defy all comprehension. Our earth alone is a huge globe nearly 8,000 miles in diameter, weighing nearly 5.5 times as much as an equal bulk of water. The sun exceeds the earth nearly 300,000 times as regards mass; and there exist at least 100,000,000 suns visible in a large telescope, some of which are larger, some smaller, than our own sun. In addition to these visible suns there is, perhaps, an even larger number of dark suns, bodies whose existence is only revealed to us when they come into collision with other bodies and produce the new stars which, from time to time, suddenly blaze in the sky.

Now, even the smallest grain of dust visible to the eye contains nearly a billion atoms of matter. How many atoms then, occur in the whole giant bulk of the earth? How many in the whole universe? If a grain of dust is a wonder heap, a structure infinite in its complexity, what shall we say about the universe?

The whole of this tremendous bulk of matter does not consist of the same stuff throughout. Chemists have shown that there exist some eighty or ninety distinct kinds of matter termed elements. Everything we see about us on the earth is built up of atoms of these different elements, and the spectroscope tells us that the same 80-90 elements also build up the world-systems of space.

Chemistry is the science which explores this unknown world of atoms. In the following chapters will be told the wonderful story of how man has succeeded in penetrating this universe of the infinitely small, and how he has actually determined the size, shape, and structure of particles

so tiny as to be invisible even under the most powerful microscope ever invented. The chemist of to-day can confidently follow the unseen motions of a realm which the scientists of a few decades ago had thought for ever unexplorable to the intellect of man.

CHAPTER II

THE UNDERWORLD OF ATOMS

ALL matter is slowly changing. In the whole of nature there is not a single particle in a state of rest. Not a single object existing now will exist a few million years hence. Tennyson was conscious of these grand cosmic changes that are continually altering the surface of the earth when he wrote :—

> " The hills are shadows and they flow
> From form to form and nothing stands ;
> They melt like mist, the solid lands
> Like clouds they shape themselves and go."

The Greeks were extraordinarily close observers of nature, and the eternal changes going on in her did not escape them. Thus there sprang up, over 2,300 years ago, a series of great thinkers, Leucippus, Democritus, and Epicurus, who traced this perpetual change to the motions of the tiny atoms of which matter is built. The views of Democritus, as elaborated by Epicurus, were centuries later described by the Roman, Titus Lucretius Carus (98-54 B.C.), in a poem " De Rerum Natura," and surely never before and never since has a theory of the universe been set forth in a form so resplendent with imagery. In this poem we catch a glimpse of that grandeur of the old Greek poetry, which is now for the most part lost ; and we realise how boldly and with what scientific imagination these old-world thinkers looked into Nature's hidden underworld, and, like Tennyson in our own time

> " Saw the flaring atom streams
> And torrents of her myriad universe,
> Ruining along the illimitable inane,
> Fly on to crash together, and make
> Another and another frame of things
> For ever."

According to Lucretius the whole universe consists of innumerable multitudes of atoms, extending far beyond the limits of our visible world and filling all the depths of space. These atoms are not at rest; far from it; they are falling silently downwards like snowflakes on a winter's day, through immeasurable intervals of space and time. In one vast moving stream of innumerable myriads they come, sweeping out from the heights of unknowable immensity above into the infinite depths below; without end or beginning, night and day, year in year out, for all time and through all space, this mighty fall continues. The atoms, however, do not fall straight down; for if they did "they would all fall down" as Lucretius wrote, "like drops of rain through the deep void, and no clashing would have been begotten, nor blow produced from the first beginnings; thus nature would never have produced aught." Consequently, the atoms as they fall swerve slightly from their paths; they clash together and entangle themselves in groups; then group reacts on group and sets up whirlpools of rotating atoms, something after the nature of the astronomers' nebulæ of to-day.

From such vast whirling eddies of atoms are formed not only the solid objects on the earth, but even the earth itself and the heavenly bodies. As everywhere throughout all space the same conditions are repeated, so must the phenomena be repeated also. Above us, below us, beside us therefore, are worlds without end. Some are great, others small; some are in the process of formation, and others, through collision, are being destroyed. Some have many moons, others none; some even are devoid of water. But they have all one fate in common, they are all transient. These worlds come and go, attracting new atoms out of limitless space or dispersing their own particles; thus the universe is in a state of flux in every part. All things are fading or growing like clouds in a summer's sky.

According to Lucretius, the atoms are of different shapes and sizes, as well as eternal and indestructible. Though ancient systems may be dissolved and new systems evolved out of their ruins, the atoms out of which these systems

are built continue to this day as they were created, unbroken and unworn, perfect in number and weight. They are so tiny that no mortal eye can ever behold them; they must be so small because, as Lucretius told us :—

"After the revolution of many years a ring is thinned on the underside by wearing, the dripping from the eaves hollows a stone, the bent ploughshare of iron imperceptibly decreases in the fields, and we behold the stone-paved streets worn down by the feet of the multitude. . . . These things we see are lessened, after they are thus worn down; but what bodies depart at any given time nature has jealously shut out the means of seeing. Lastly, the bodies which time and nature add things to little by little, constraining them to grow in due measure, no exertion of the eyesight can behold; and so too, wherever things grow old by age and decay, and when rocks hanging over the sea are eaten away by the fine spray, you cannot see what they lose at any given instant. Nature therefore works by unseen bodies."

This smallness of the atoms explains why it is that although the atoms which build up a body are in swift motion yet the body itself is seen to rest in supreme repose unless it exhibits motion as a whole;

"For," as Lucretius adds, "the atoms lie far away from our senses, beneath their ken; and therefore since they are themselves beyond what you can see, they must withdraw from sight their motions also; and the more so since the things which we can see, do often conceal their motions when a great distance off. For often the woolly flocks as they crop the glad pastures on a hill, creep on whither the grass jewelled with fresh dew summons and invites each, and the lambs fed to the full gambol and playfully butt; all which objects appear to us from a distance to be blended together and to rest like a white spot on a green hill. Again when mighty legions fill with their movements all parts of the plains, waging the mimicry of war, the glitter then lifts itself up to the sky and the whole earth round gleams with brass and beneath a noise is raised by the mighty trampling of men, and the mountain side stricken by the shouting re-echoes the voices to the stars of heaven, and horsemen fly about and suddenly wheeling scour across the middle of the plains, shaking them with the vehemence of their charge. And yet there is some spot on the high hills, seen from which they seem to stand still and rest on the plains as a bright spot."

Modern science now tells us that this reasoning is correct, the motion of molecules in the case of solid bodies being confined within so narrow a range that even with our best

microscopes we cannot detect that they alter their places at all. Lucretius illustrated the ceaseless whirl and the eternal clash of the atoms which make up all bodies about us by the familiar spectacle of motes dancing in a sunbeam ; he wrote :—

" Of this truth . . . we have a representation and picture always going on before our eyes and present to us ; observe whenever rays are let in and pour the sunlight through the dark chambers of houses : you will see many minute bodies in many ways through the apparent void mingle in the midst of the light of the rays, and as in never ending conflict skirmish and give battle, combating in troops and never halting, driven about in frequent meetings and partings."*

But here we must stop ; for enough has been said to show the reader that Democritus was the greatest of the ancient thinkers, whose views, obscurely expressed by partisan philosophers, more closely approximate in their grandeur and loftiness to modern theories than those of any of his successors for the space of nearly two thousand years after his death. Not only did he clearly set forth the atomic theory now universally acknowledged, but he, as we have just seen, believed the sun to be of enormous size, that the Milky Way consisted of suns, and that the number of worlds was infinite—ideas finally arrived at only within the last couple of centuries by European scientists !

For two thousand years these speculations of the Greeks remained buried and almost forgotten. Newton was acquainted with them and appeared to have accepted the idea that all bodies are made up of hard indestructible particles. " It seems," says Newton, " probable to me that God in the beginning formed matter in solid, hard, impenetrable, movable particles, of such sizes and figures, and with such other properties, and in such proportion, as most conduced to the end for which he formed them ; and that these solid particles, being solids, are incomparably harder than any porous bodies compounded of them ; even so very hard as never to wear or break in pieces, no ordinary power being

* The reader will find an interesting account of the earlier chemical theories in Ida Freund's " The Study of Chemical Composition," and in Muir's " History of Chemical Laws and Theories."

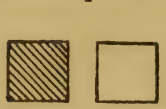
able to divide what God himself made one in the first creation."*

It is, however, to Dalton and to him alone that the honour of founding a CHEMICAL atomic theory is to be ascribed. It had long been known that, just as men and women are attracted to each other and unite as husband and wife, so also in the atomic world the atoms combine to form little groups called "*molecules*." The molecules are, so to speak, the planetary systems which build up all the objects around us. Now it was Dalton who discovered in 1803 that there was as little chance or haphazard in the concourse of the atoms as in the motions of the planets. Before his time it had been well known that chemical compounds, that is substances resulting from the union of the atoms of two or more elements, have a fixed composition. In other words a chemical compound is not a product like a plum pudding, in which the proportion of the ingredients which make it up can be varied considerably without much affecting its properties. Quite otherwise. We cannot vary even in the slightest degree the ratio in which the elements are combined in a true compound. This fact is known in chemistry as the *Law of Constant Proportions*. Dalton's great discovery was the *Law of Multiple Proportions*. This is best explained by means of an example. Iron can combine with sulphur in two proportions to form two different compounds, one a black body called ferrous sulphide, the other a brass-like substance called iron pyrites. When these bodies are analysed a very remarkable fact comes to light. The first body consists of *ONE* part of sulphur combined with 1.74 parts of iron. The second body consists of *TWO* parts of sulphur combined with 1.74 parts of iron. So that the amount of sulphur combined with the *same weight* of iron in the two compounds is *EXACTLY* in the ratio 1 : 2, *i.e.* in the ratio of *simple whole numbers*. Again, nitrogen combines with oxygen to form several different bodies, and the weights of oxygen which are united with 1.75 parts of nitrogen are, 1, 2, 3, 4, 5, respectively, in the successive compounds. Here again the ratio of the weights of oxygen which are combined

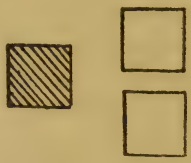
* Horsley's "Newton," Vol. 4, p. 260.

with a fixed weight of nitrogen, are simple whole numbers. Now Dalton showed that this was a general law, which may be stated thus: *Whenever two elements unite to form several different compounds, the ratios of the different weights of the first element which unites with a fixed weight of the second are always simple WHOLE numbers.*

Why the ratios should be *exactly* whole numbers and not fractional, seemed an inexplicable mystery until Dalton showed that it was a necessary consequence of the atomic theory. In the case of iron, for example, we have the following two compounds produced by the union of atoms of iron and sulphur.



Iron. Sulphur.



Iron. Sulphur.

Since two atoms of sulphur weigh exactly twice as much as one, it is obvious now that the ratio of sulphur combined with the same weight (for example, one atom) of iron must be in the ratio 1 : 2, *i.e.* exactly whole numbers.

Dalton's great feat was the application of the atomic theory to chemistry. Although the ancient theory of the structure of material things had predicated differences in the sizes and weights of the different kinds of atoms, yet Dalton was the first who demonstrated that it is actually possible to determine the relative weights of the atoms of elements, and the number of atoms which constitute the ultimate particles of compounds. The theory, however, was not launched perfect into the world; it still contained many grave errors and uncertainties. Dalton, for example, had imagined that the elementary gases like oxygen or nitrogen consisted of single atoms moving about rapidly; but in 1811 Avogadro, an Italian physicist, showed that what Dalton had called an "atom" usually consisted of two separate atoms united together and accompanying each other on their journey through space, like man and wife or earth and moon.

Again, it had been known for some time that water consists of 8 parts of oxygen united with 1 part of hydrogen. Dalton asserted that water consisted of one atom of oxygen united with one atom of hydrogen, and that therefore the atom of oxygen weighed 8 times as much as the atom of hydrogen. Avogadro, however, showed that water, in reality, consists of two atoms of hydrogen united with one atom of oxygen, and that therefore an atom of oxygen weighs 16 times as much as an atom of hydrogen. The Italian was thus the first to point out the modern distinction between "atom" and "molecule"; it was he who showed clearly how the relative weight of the different kinds of atoms and molecules may be determined with certainty and without ambiguity. "An atom," says Maxwell,* "is a body which cannot be cut in two. A molecule is the smallest possible portion of a particular substance. No one has ever seen or handled a single molecule. Molecular science, therefore, is one of those branches of study which deals with things invisible and imperceptible by our senses, and which cannot be subjected to direct experiment. . . . Molecule is a modern word. It does not occur in Johnson's Dictionary. The ideas it embodies are those belonging to modern chemistry. A drop of water . . . may be divided into a certain number, and no more, of portions similar to each other. Each of these the modern chemist calls a molecule of water. But it is by no means an atom, for it contains two different substances, oxygen and hydrogen, and by a certain process the molecule may actually be divided into two parts, one consisting of oxygen and the other of hydrogen. According to the received doctrine, in each molecule of water there are two atoms† of hydrogen and one of oxygen. . . . We now see what a molecule is as distinguished from an atom. A molecule of a substance is such a small body that if, on the one hand, a number of similar molecules are assembled together they would form a mass of that substance, while on the other hand, if any portion of this molecule were removed

* "Scientific Papers," Vol. 2, p. 361.

† Maxwell here says "molecules." I have ventured to alter the word to "atom" in conformity to modern usage.

it would no longer be able, along with an assemblance of other molecules similarly treated, to make up a mass of the original substance. Every substance, simple or compound, has its own molecule. If this molecule be divided, its parts are molecules of a different substance or substances from that of which the whole is a molecule. An atom, if there is such a thing, must be a molecule of an elementary substance."

Avogadro's ideas were not accepted until nearly half a century after his death.

For many years after Dalton's time the atomic theory was still in a very imperfect condition. Such incredible qualities, as infinite smallness, absolute hardness, and indivisibility, were attributed to the atoms that many reasonable naturalists were inclined to doubt whether they were real entities at all. Even in the early days of the theory, however, many first-class intellects were pondering over these problems. If atoms are infinitely small, why are not all chemical reactions infinitely swift? asked Sir William Thomson; and he suggested that atoms are real portions of matter occupying a finite space and forming a not immeasurably small constituent of any palpable matter. Proof after proof of the fundamental correctness of this view gradually collected. First of all Loschmidt in 1865 showed how it followed from the kinetic theory of gases that molecules have a sensible diameter, and he actually deduced a numerical value for it. Then Johnstone Stoney in 1868, and later, Sir William Thomson in 1870, published results of a similar kind,—those of Thomson being deduced not only in this way, but from considerations derived from the thickness of soap bubbles, and from the electric action between zinc and copper.

The diameter and mass of a molecule, as estimated by these methods, are very small, but by no means infinitely so. About two millions of hydrogen molecules in a row would occupy a millimetre (25.4 millimetres going to an inch), and two hundred million million million of them would weigh a milligramme. "To form some conception," says Thomson," of the degree of coarse-grainedness indicated

by this conclusion, imagine a rain drop, or a globe of glass as large as a pea, to be magnified up to the size of the earth, each constituent molecule being magnified in the same proportion. The magnified structure would be more coarse-grained than a heap of small shot, but probably less coarse grained than a heap of cricket-balls."*

Dr. Johnstone Stoney (*Phil. Mag.*, 1868, Vol. XL., p. 382) employs the following remarkable illustration of the size of the molecules :—

"A cubic millimetre, the volume of a small pin's head, if each of its edges were magnified 10^{10} times (*i.e.* 1 followed by 10 noughts), would become almost as huge as the earth. Under the same circumstances molecules of air would be spaced at intervals averaging 10 metres (nearly 11 yards). And 700 metres would have to become the mean distance to which they would have to travel between their encounters. On this great scale it would not be inappropriate to use men or other animals to represent the individual molecules—their hearts beating, their chests heaving, their limbs in vigorous motion, to represent their internal events (motions). And as to the motions with which the molecules of a gas dart about among one another, these as they exist in common air would have become journeys as long and of as various lengths as the streets of a great city, while the widths of the streets may stand for the intervals at which the representatives of the molecules are to be spaced asunder at starting. In this model we have applied so much more magnification to time than to space that all the velocities come out 60,000 times slower than in nature. Accordingly our animated molecules may be conceived as quietly gliding along the journeys they have to make between their encounters; for the mean duration of a journey is to be a day and the average speed must accordingly be only half a metre a minute—on the supposition that our model is to represent what occurs in a gas as dense as air and at its temperature and pressure. It thus appears that we must conceive them as requiring on the average about a quarter of an hour to get past each house in the streets along which they have so slowly to make their way. A model of this kind is not without its use, if only as a means by which we can gain a lively perception of how considerable the events going on within the molecules may be when compared with the motion of translation of the molecules."

Molecular science thus brings us face to face with the mystery of living matter; it forbids the physiologist from imagining that structural details of molecular dimensions

* *Nature* (1870).

can furnish an explanation of the infinite variety which exists in the properties and functions of the most minute organisms.

For, according to Clerk Maxwell,* the smallest living germ visible under the microscope contains barely a million organic molecules,—a number far too small to form a being furnished with a whole system of specialised organs. Yet from this germ will develop a highly organised animal and from another germ, equally microscopic, will develop another animal of a totally different kind—an idea well expressed by Sir Lewis Morris in the words :—

> " Within the germ the molecules fare free,
> Holding the potency of what shall be ;
> Within the little germ lurks the heaven-reaching tree."

We may therefore well ask, Can all the differences, infinite in number, which distinguish the one animal from the other, arise each from some difference in the molecular constitution of the respective germs, structures containing barely a million molecules ? This seems scarcely possible. It appears, therefore, that life must take its rise in a world beneath the atom, a world composed of particles as small in relation to the atoms as the atoms are small in relation to ordinary matter particles. †

Science has done more than measure the mass and size of particles so small as to be absolutely invisible under the best microscope. She has also measured the velocity with which these particles move. According to the molecular theory all gases consist of molecules flying about in all directions with great speeds. At each instant an incredibly vast number crash up against the walls of the vessel containing the gas, and thus communicate to them a series of impulses which follow each other in such rapid succession that they produce an effect which cannot be distinguished from that of a continuous pressure. This is the reason why air or other gas placed in a vessel presses against the sides of the vessel ; and from a knowledge of the

* " Scientific Papers," Vol. 2, p. 461.

† See an interesting correspondence in *The Times*, May 30 to June, 1910, between Francis Galton, Lancester, Pearson, and others.

pressure and the mass of gas producing it, we can calculate the velocity of the gaseous molecule. Let us take the best ascertained case,—that of hydrogen gas. A cubic centimetre of hydrogen gas, at the temperature of melting ice and at a pressure of one atmosphere, weighs 0.000,089,54 grams. We have to find out how fast this small mass must move (whether together or in separate molecules makes no difference) so as to produce the observed pressure on the sides of a cubic centimetre. The result is 1,859 metres a second—over a mile a second. This is a very great velocity. Even the swiftest rifle bullet does not fly at this rate.

In other gases the velocity is less. In the case of air it is something like 17 miles a minute.

Consider for an instant what this means. If all the molecules in the air we breathe were flying in the same direction they would constitute a wind blowing at the rate of seventeen miles a minute. Such a wind has the force of a gunpowder explosion. If it struck us it would instantly tear us limb from limb and pulverise our bodies. Only the fiery blast from a cannon's mouth rushes forth with such a velocity. How then are we able to exist in the midst of this storm of crashing molecules? Only because they happen to be flying in different directions, so that those which are beating against our backs enable us to support those which are flashing against our breasts. Indeed if the molecules were suddenly to cease their terrific bombardment, our veins would swell out and burst, the breath would rush from our bodies, and we should instantly expire.*

Tremendous as the velocities reigning in the molecular world may seem to us at first sight, yet they are quite insignificant when compared to the swiftness of the whirling motions going on within the atoms themselves; the particles building up the atoms flash through over a HUNDRED THOUSAND MILES A SECOND! Incredible! you will say; nevertheless it is a sober fact of science. In every stone and in every stick about us, ceaselessly, second by second, day by day, century by century, age by age, these

* Clerk Maxwell, "Scientific Papers," Vol. II., p. 366.

terrific motions are going on. In the tiniest grain of dust in the millionth part of a second the rush of atomic events is so incredibly swift as to defy all conception and calculation.

We have seen above that the apparent repose of the objects about us is a false impression, arising from the inability of our unaided senses to perceive atomic motion. We know, for example, that a regular volcanic action must be going on all over the surface of an apparently smooth sheet of water. Billions of atoms must be rushing upwards each second from each part of the surface, churning it up into a million jetting fountains ; and billions of molecules must be simultaneously showering downwards, setting up in it violent wave motions and eddies.

The smoothest water surface therefore must, if magnified sufficiently, look like a sea torn up and shattered by a tornado.

Dr. Brown, nearly a century ago, was the first who experimentally demonstrated the existence of this molecular motion in water. He suspended very tiny drops of oil in water and then examined the mixture through a very powerful microscope. The individual drops, instead of remaining quietly at rest, were seen to be continually agitated with small but rapid oscillatory motions. Since the smallest drop of oil visible under the microscope must have contained something like 50,000,000 molecules, we can form some idea of the violent movement which must be going on among the neighbouring water molecules in order to set into motion such, relatively speaking, bulky masses.

Recently a method has been discovered which allows us to observe the motion of particles far smaller than these tiny oil-drops, particles whose magnitudes actually approach those of the larger known molecules. Indeed, it is claimed that the large molecules of albumen and certain fluorescent substances have actually been seen.

The principle of this new and beautiful instrument, called the ultra-microscope, is as follows :—Before we can see an object it must reflect to us the light by which we see it. Objects which reflect no light are invisible. Now a grain of sand will not reflect an ocean wave because it is too small

in respect to it. The wave simply embraces the sand and passes on. In the same way particles much smaller than waves of light will not reflect them at all and so cannot be seen in the strongest microsope. In fact it has been proved that the smallest particles which can be seen in the best modern microscopes are about $\frac{1}{7000}$th of a millimetre in diameter, just about half the length of a wave of visible light. We can never hope, therefore, to see directly a particle as small as a molecule, since these are many thousands

FIG. 2.—Use of the Ultra Microscope.

of times smaller in diameter than the length of a wave of light.

The case is otherwise, however, if we make these particles emit a light of their own. Then we may get from them the light necessary to see them.

In order to do this a beam of sunlight is brought to a focus in the liquid containing the particles. The apex of this cone of light is observed by a special microscope ; the intense beam of light falling on the particles sets them into a vibra-

tion so intense that they emit a light of their own by which they may be seen.

Zsigmondy* obtained suspended in water gold dust so fine that many particles could not have contained more than a few dozen molecules. On looking at these tiny particles through the ultra-microscope, he saw them in swift motion.

"The tiny gold particles did not swing stationary in the water, they moved with astonishing rapidity. He who has seen a swarm of flies dancing in the sunlight can obtain a notion of the motions of these tiny gold particles; they hop, dance, spring, crash together and fly apart so rapidly that the eye can hardly make out their movements. . . . These motions show that there is a continual mixing together of the interior parts of every liquid, going on unceasingly, year in, year out. . . . The smallest observable gold particles show a double motion; firstly they possess a motion of translation so rapid that the particles travel 100 to 1000 times their own diameter in $\frac{1}{7}$ to $\frac{1}{8}$ of a second; secondly, they possess a swinging or oscillatory motion of much shorter period; indeed it is probable that they possess oscillatory motions of higher order and smaller amplitude, too small and too rapid for direct observation."

The appearance of a similar silver dust in water is described as follows:—

"One would never guess what a wonderfully beautiful play of colours is given out by this ordinary looking liquid when viewed through the ultra-microscope. Blue, violet, green, and red particles, in different shades and with a rare brilliancy of colour, are seen in ceaseless movement. One particle approaches the other, circles round it in a rapid zig-zag movement, and then flies off again. Sometimes several particles group together and dance like flies in the sunshine, especially when for a fraction of a second one particle comes near another."

Zsigmondy thus describes the effect of adding a little sodium nitrate to a clear gold solution so as to make the particles of gold coagulate:—

"Suddenly there appeared yellow balls of mist, in a state of wave motion. The mist condenses further. One sees the tiny individual particles in a state of lively Brownian movement. The particles rush

* Zsigmondy, "Kolloidie und Ultramicroskopie" (1905). z.f. Elektrochemie viii. 684-87 (1902). z.f. Physik. Ch. lvi. 65-82 (1906). An American translation of these researches has recently appeared.

together and revolve round their common centre of gravity. . . if the saltpetre solution be allowed to flow into the gold solution under the microscope, such rapid and violent whirlpool motions are set up that the eye is unable to follow the process of coagulation."

The motions thus revealed in Zsigmondy and Siedentopf's researches must be regarded as the beginnings of the finer and swifter molecular motion going on in all bodies about us. The molecules themselves must, at ordinary temperatures, move so rapidly (some hundreds of yards a second) that it would be impossible to follow them with the eye, even if we had the means of visualising their motion. By intense cooling, however, it might be possible to slow down their motion and thus render them accessible to human observation.

In science nothing is impossible. The nineteenth century witnessed the performance of what philosophers had long considered utterly impossible, namely, the chemical analysis of the sun and stars, bodies millions of miles distant. Will not the twentieth century witness a similar triumph, that is, the revelation to the eye of the swift-moving atomic universe by which we are surrounded?

We now propose to give the reader a glimpse of a wonderful realm of science, a realm which one would have thought must for ever have remained unexplored by the intellect of man. No one in his wildest dreams would ever have conceived that chemists could determine the actual shape of particles so small that the largest probably possesses a diameter far less than the $\frac{1}{25000000}$ part of an inch (10^{-8} cm.), particles far smaller than the very light waves by which we see, so small that we can never hope to catch a glimpse of them in the very best modern microscopes. And yet this has been achieved, and is, perhaps, one of the most wonderful feats of the nineteenth century. Like all great discoveries, however, the principles upon which it rests are simple in the extreme, as we will immediately show.

Each atom attracts to itself one or more little electric moons or satellites, which form the centres to which other atoms are attached when the atom enters into chemical combination. Now these tiny electrified particles mutually

repel each other, and they consequently take up places on the surface of the atom equidistant from each other, and so give the atom a definite shape. We will take the case of the best studied atom—that of the element carbon. This atom is tetravalent; in other words it can combine simultaneously with four atoms like those of hydrogen or chlorine. Consequently it possesses four of these electrified particles—electrons we will call them henceforth—attached to it, which by their mutual repulsions assume the positions shown in Fig. 3; that is to say, they occupy the corners of a tetrahedon, as the figure marked out by the dotted line is called.

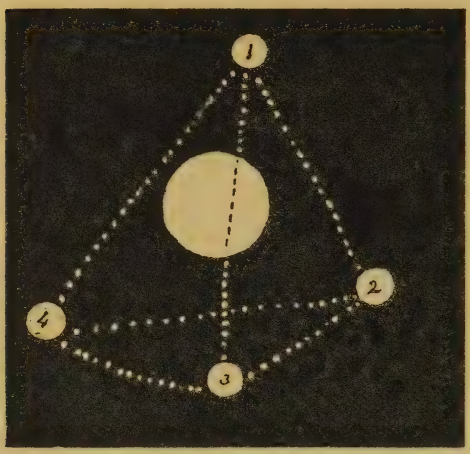


FIG. 3.—Shape of the Carbon Atom according to the Modern Electron Theory. Four electrons, 1, 2, 3, 4, mutually repel each other into the corners of a tetrahedron, the centre of which is occupied by the carbon atom.

These electric charges, by their attraction, cause other atoms to cling to them; and in this sense the carbon atom may be said to possess a definite shape—that of a tetrahedon. It must be remembered, however, that it is not the shape of the carbon atom, but rather the distribution of its electric charges that we are, in reality, investigating. Nor must it be supposed that these electrons are motionless. Quite the contrary. We know that they are whirling with enormous speeds—almost with the velocity of light itself—round little orbits about fixed points on the carbon atom. In fact the tiny atoms are alive with motion and undoubtedly possess very complex structures. This conclusion is supported by the extremely complex nature of the light they give

out—as will be shown later. This is the view now adopted by the majority of chemists.

However, some of the great organic chemists—Wislicenus, for example—have thought that the actual shape of a carbon atom is that of a tetrahedron, being composed of great multitudes of tiny particles of matter clustered together in that form. We have drawn the carbon atom after the ideas of Wislicenus (Fig. 4).

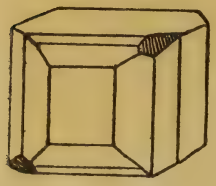
FIG. 4.—Shape of the Carbon Atom according to Wislicenus. He supposed that the carbon atom was built up in the form of a tetrahedron, as shown, by the aggregation of a large number of small particles.

The reader, however, should not go away with the idea that the shape of the carbon atom is necessarily the same at all temperatures and pressures and under all conceivable conditions. Professor J. J. Thomson (*Phil. Mag.* 1904, Vol. 7, p. 265) has shown that if a system containing four electrons at the corners of a tetrahedron be caused to rotate very rapidly, they would pass to the corners of a square, thus—

On the motion gradually slowing down, this position would become unstable, and the particles would suddenly revert to their original positions at the corner of a tetrahedon.

When an element changes its valency, or power of combination, it also must necessarily change its shape. No doubt very high temperatures, perhaps even immense pressures,

alter the properties of the elements entirely. When we send a beam of plane polarised light (that is, one in which the ether particles all oscillate in one plane) through certain substances we often find that the vast whirling motions going on within the molecules of the substance caused the beam to issue with its plane of polarisation rotated through an angle. Suppose now we take a substance whose molecules consist of a central atom of carbon, to which are attached four different atoms or atomic groups, which we will call R_1, R_2, R_3, R_4, thus :—



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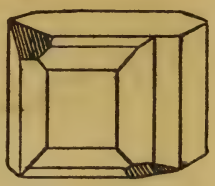
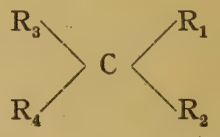


B

FIG. 5.

Crystals which when dissolved in water turn the plane of polarisation to the right.

Crystals which when dissolved in water turn the plane of polarisation to the left.



Then we find that nearly always there exist two sorts of molecules, chemically alike, but which differ in the following respects :—

The first sort, when dissolved in water, rotate the plane of polarisation from left to right ; whereas the second sort rotate it from right to left—in the opposite direction, and to the same extent as well.

Moreover it sometimes happens that the two substances differ from each other in the same way that the right hand differs from the left. Fig. 5 shows the crystals of one of these substances, known as potassium tartrate. One is the mirror image of the other. From this Pasteur, who discovered the fact, drew the inference that the difference between the two varieties must be due to the different arrangement in space of the atoms in the molecules of the two crystals. But it was Le Bel and van't Hoff who directly connected this fact with the shape of the carbon atom. Thus in Fig. 6; if we suppose each of the atoms to be

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arranged round the carbon atom as in (1) ; then in (2) the atoms would be arranged round in a directly opposite way, so that (1) is a mirror image of (2). This is, probably, the explanation of this remarkable effect. But the reader must also remember that the exact nature of the cause which determines that the light should be rotated from its original plane of polarisation is hardly known at all. There must be a vast atomic whirl going on in the first case from left to right, and in the second from right to left. The medium is, as it were, twisted in opposite directions in the two cases.

Nor is the element carbon alone in this respect. The classical researches of Kipping, Pope, and their pupils have shown that . . . the atoms of such bodies as silicon, tin, sulphur, and nitrogen all exhibit " optical activity," as the phenomenon is called, and so possess a definite shape.

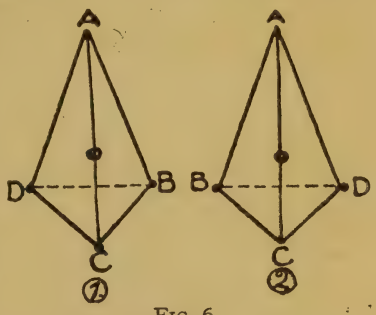


FIG. 6.

Of course, before optical activity can be exhibited, the various atoms must be attached stably to the central atom, so that they cannot move over its surface and interchange places. In many cases where the atoms are light, they move so freely over the surface of the central atom and so easily interchange their relative positions that optical activity under such circumstances is quite impossible, or if attained, rapidly and spontaneously disappears.

There exist many other cases where the ordinary plane formulæ are unable to explain the properties of certain compounds. Their peculiar behaviour, both as regards their chemical and physical properties, can only be understood on the assumption that they arise out of the different positions in space of the atoms in their molecules. Out of these facts has grown the fascinating science of " Stereo-Chemistry," but it is far too large a subject to be further dealt with here.

I hope my reader now realises what a wonderful structure a tiny molecule must possess. Within this tiny scrap of matter lies hidden a whole universe in a ceaseless and terrific movement. In Professor Shenstone's words. "The atoms move within the molecules, perhaps like the members of the heavenly systems—or as suggested years ago by the late Professor Williamson, they may even move from molecule to molecule in an unending course of migrations! If so . . . stereo-chemical formulæ will have to be replaced, sooner or later, by living pictures, for which models may perhaps be found in the constellations which glorify the heavens."*

* (Shenstone, "The New Chemistry and Physics," p. 286). Published by Smith, Elder & Co., London.

CHAPTER III

DISTRIBUTION AND EVOLUTION OF THE ELEMENTS

THE search for that which remains unchanged beneath the ceaseless flow of chemical change is as old as human thought itself, and deeply troubled

> " The hoary thinkers of the Past
> Whose dim vast thoughts, to too great stature grown
> Flashed round as fitful lightning flashes round
> The black vault of the unknown."*

After many thousands of years of experiment and specu lation, it has come to be recognised within the last two or three hundred years that all the changing forms of matter about us are composed of changeless kinds of matter called " Elements." A chemical element may be defined as a substance which, though it may pass through many trans-formations, is always recoverable undiminished in quantity from any chemical combination into which it may enter, and is not by any known means resolvable into two or more kinds of matter. Gold, for example, is regarded as an element because from it nothing can be extracted that is not gold ; in other words it is homogeneous, and consists in its most minute parts of one kind of substance.† Water, and iron rust, however, are compounds, because in proportion as they are destroyed by suitable means, two kinds of new matter make their appearance, and the united weights of the products of decomposition are equal to the weight of the " compound " body from which they are produced.

The materials from which this grey old world of ours and its inhabitants are built up may be resolved into some eighty

* Sir Lewis Morris, " The Wanderer." (Published by Kegan Paul, Trench & Co.)

† To what extent this definition of an element must be modified owing to the discovery that certain elements like radium are decom-posing slowly will be seen later.

odd elements, a list of which, together with their symbols and atomic weights, is here appended.

LIST OF ELEMENTS

With their Symbols and Atomic Weights.

		O = 16.			O = 16.
Aluminium	Al	27.1	Molybdenum	Mo	96.0
Antimony	Sb	120.2	Neodymium	Nd	144.3
Argon	A	39.9	Neon	Ne	20
Arsenic	As	75.0	Nickel	Ni	58.68
Barium	Ba	137.37	Nitrogen	N	14.01
Bismuth	Bi	208.0	Osmium	Os	190.9
Boron	B	11·0	Oxygen	O	16.00
Bromine	Br	79.92	Palladium	Pd	106.7
Cadmium	Cd	112.40	Phosphorus	P	31.0
Cæsium	Cs	132.81	Platinum	Pt	195.0
Calcium	Ca	40.09	Potassium	K	39.10
Carbon	C	12.00	Praseodymium	Pr	140.6
Cerium	Ce	140.25	Radium	Ra	226.4
Chlorine	Cl	35.46	Rhodium	Rh	102.9
Chromium	Cr	52.1	Rubidium	Rb	85.45
Cobalt	Co	58.97	Ruthenium	Ru	101.7
Columbium	Cb	93.5	Samarium	Sa	150.4
Copper	Cu	63.57	Scandium	Sc	44.1
Dysprosium	Dy	162.5	Selenium	Se	79.2
Erbium	Er	167.4	Silicon	Si	28.14
Europium	Eu	152.0	Silver	Ag	107.88
Fluorine	F	19.0	Sodium	Na	23.00
Gadolinium	Gd	157.3	Strontium	Sr	87.62
Gallium	Ga	69.9	Sulphur	S	32.07
Germanium	Ge	72.5	Tantalum	Ta	181.0
Glucinum	Gl	9.1	Tellurium	Te	127.5
Gold	Au	197.2	Terbium	Tb	159.2
Helium	He	4.0	Thallium	Tl	204.0
Hydrogen	H	1.008	Thorium	Th	232.42
Indium	In	114.8	Thulium	Tm	168.5
Iodine	I	126.92	Tin	Sn	119.0
Iridium	Ir	193.1	Titanium	Ti	48.1
Iron	Fe	55.85	Tungsten	W	184.0
Krypton	Kr	81.8	Uranium	U	238.5
Lanthanum	La	139.0	Vanadium	V	51.2
Lead	Pb	207.10	Xenon	Xe	128
Lithium	Li	7.00	Ytterbium (Neoytterbium)	Yb	172
Lutecium	Lu	174	Yttrium	Y	89.0
Magnesium	Mg	24.32	Zinc	Zn	65.37
Manganese	Mn	54.93	Zirconium	Zr	90.6
Mercury	Hg	200.0			

These elements occur in very unequal proportions. Some are so rare and costly that no man has ever gathered more than a trace of them; others are so plentiful that they surround us on all sides on land, sea, and sky in innumerable millions of tons, and awaken our astonishment by their very abundance. The solid crust of the earth is composed of eight principal elements, namely, oxygen (47%), silicon (28%), aluminium (8%), iron (5%), calcium (3½%) magnesium (3%), potassium (2.3%) and sodium (2.6%). Besides these there occur traces of all the others mentioned in our list. This distribution of elements holds only for the outer crust of the earth. When we go deep down into its interior the distribution alters entirely. The subject has been discussed recently by the Swedish chemist Arrhenius* who shows that we have good reason to believe that the earth is a huge metallic ball, white hot, even gaseous, in the inside. In its deepest depths have gravitated together the heaviest metals like gold and silver. It will probably excite the cupidity of the purse-proud to know that the centre of the earth may well be one stupendous gold nugget, or may consist of millions upon millions of tons of this and other costly metals. Above this core comes a vast layer of metallic iron. Probably about half the giant bulk of the earth consists of metallic iron. The raging white heat of a great iron smelting furnace is as nothing when compared to the temperatures reigning within the great furnaces of the earth's depths; there gleam vast masses of iron heated

* "Zur Physik des Vulcanismus," Geol. Foren. i Stockholm Forhand. 22 (1900), pp. 395-419. "Das Werden der Welten" (Leipzig, 1908), p. 1.

To the list on previous page must be added *Asterium* and *Nebulum*, light elements unknown upon the earth, which occur in very hot stars and nebulæ; also *Coronium*, a light element occurring in the sun's corona.

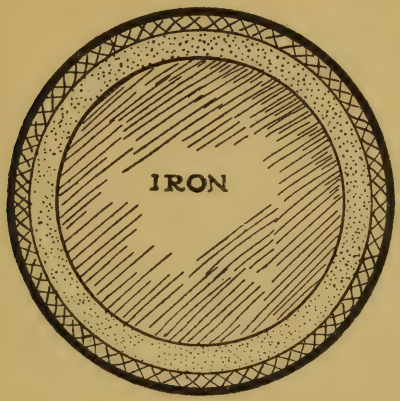
NOTE.—As originally defined the atomic weight of an element meant the number of times its atom outweighed the hydrogen atom, but, for various reasons, it is now found more convenient to fix the atomic weight of oxygen as 16 and that of hydrogen as 1.008, and express the weights of the other elementary atoms relative to Oxygen 16.

so strongly as to be in a gaseous state, yet compressed with such tremendous force as to be denser than solid steel. Of the whole 8,000 miles of the earth's diameter, no less than 6,000 are supposed to consist of this gaseous iron sphere. This is followed by a layer, 600 miles thick, of gaseous rock-magma. Then comes a layer 160 miles thick of molten white-hot rock, and finally comes the solid crust on which we live and which cannot be more than 100 miles thick, and in most parts of the earth is much less than 30 miles thick.

We have good reason to believe from many facts, astronomical and geological, that the bulk of our earth is iron. For example, the fragments of matter which wander through the waste spaces of the universe, and finally fall upon the earth as meteorites, usually consist of metallic iron mingled with small quantities of metals like calcium, nickel, cobalt, aluminium, and non-metals like sulphur, phosphorus, oxygen, carbon, and other materials or gases. Now meteorites are composed of dust collected from millions and millions of suns during millions and millions of years. From every sun and from almost every world in this vast universe of ours there escape yearly into space thousands of tons of dust particles. These particles are shot out from suns during the titanic explosions which are continually convulsing their surfaces; from the colder worlds they are hurled forth into space amidst the thunder of volcanic explosions. Once these particles get free into space they are, according to Arrhenius, driven away from the suns into the deepest depths of the universe by the pressure of the light falling on them, the light pressure overbalancing the attractive force of gravitation when the mass of the particles falls below a certain value. In the waste spaces of the universe these tiny particles gravitate together and form, among other things, meteorites. Now since meteorites are formed from matter derived from the most various celestial bodies during almost an eternity of time, they must represent the average composition of celestial bodies. As meteorites are formed principally of iron it follows that the bulk of most celestial bodies is also metallic iron. There is

every reason for believing that our earth has the same composition as other celestial bodies, and that therefore it consists principally of metallic iron.

Again, in Greenland there exist strewn over the surface of the land in the neighbourhood of Disco, great blocks of metallic iron, some of them weighing many tons; and



Gaseous metallic sphere, principally iron, 6,000 miles in diameter.

Gaseous rock magma, 600 miles thick.

Molten white-hot rock, 160 miles thick.

Outer solid crust of the earth, under 100 miles thick.

FIG. 7.—Predominance of Iron in the Earth.

there is reason to believe that these did not fall on the earth from the sky as meteorites, but rather came up with the lava which overflowed Greenland in some tremendous volcanic catastrophe ages ago. These blocks, therefore, represent some of the native iron in the earth which actually found itself carried to the surface of the planet by volcanic

agency. Old volcanic rocks are always found to be impregnated with tiny particles of metallic iron which have apparently come up from below, and become entangled in the molten rock overlying the central iron core.

The fact that the earth behaves as a big magnet also points to the existence of large amounts of iron in its interior.*

A bright piece of iron left exposed to the air and damp soon turns brown, and after some time becomes entirely converted into a brown earth known as iron rust. The rust is merely a chemical compound formed by the iron uniting with an element in the air called oxygen. In just the same way part of the central mass of metals in the earth has ages ago combined with oxygen and other elements to produce the earthy crust which surrounds the earth and forms the land. Yes, the rocks, the hills, and the ground on which we tread are all more or less metallic rusts. Thus, the great hills and uplands of granite rocks are really chemical unions of metals with silicon and oxygen. In every 100 tons of these old rocks there are about 23 tons of bright shining metals like aluminium, iron, calcium, magnesium, potassium. The wonderful marble rocks, the chalk downs, and limestone peaks which cover thousands of miles of the earth's surface, are all composed of a beautiful silvery metal called calcium, combined with carbon and oxygen. Every 100 tons of marble or chalk contains nearly 40 tons of this metal. Whole mountain ranges are composed of a similar compound of the well-known element magnesium.

We now come to consider the problem of the unequal distribution of the elements. Why are some of them scattered far and wide in such enormous masses throughout the whole universe, while others occur only in the minutest traces? This question touches the deeper question of the origin of matter. Evidently we are dealing here with the handiwork of some vast cosmic law which has been operating over immeasurable intervals of space and time.

Recent researches have thrown a flood of light upon these questions. It is now believed that the elements are not the

* Arrhenius, "Das Werden der Welten," p. 17.

changeless systems that they were once thought to be, but rather systems in slow but incessant mutation.

According to Prof. J. J. Thomson, all the elements represent successive condensations of one primary stuff, whose atoms, called " electrons " or " corpuscles," weigh less than the one-thousandth part of an atom of the lightest known terrestrial element, namely, hydrogen. This primary stuff is negative electricity, which therefore is a true chemical element.* A flash of lightning consists of the swift rush of innumerable myriads of these negative electrical atoms, flying with the enormous speed of a hundred thousand miles and more a second. An electric current flowing along a wire consists likewise of a torrent of these particles flashing along between the atoms which make up the wire. Light is but the swift shudder in the ether set up by the rapid whirl of these negative electrons round their tiny orbits in the matter atoms. All the atoms of the elements consist of aggregations of many thousands of these bodies and originated in very different quantities, as follows :

In the beginning of time, long before Man, Earth, or Sun had come into existence, before even there was a suspicion of their formation, space was filled with a vast sea of electrical vapour. The vapour was composed not of atoms, for matter atoms had not yet come into existence, but of the tinier electrical particles mentioned above, the measureless speed of whose motions caused the whole to thrill with a faint crepuscular light, and appear from a great distance as a faintly luminous cloud, like one of the nebulæ which gleam nightly at us down from the sky.

The vapour, being composed of electrical atoms, was electrified beyond all measure, and stretched gleaming with its electrical fires, through the darkness of space like a flaming sword. It was the seat of inconceivable energy, of titanic forces, and, in Tennyson's words, our world and sun and the elements which build us up, took their birth

* Sir William Ramsay, Trans. Chem. Soc., 1908, 93, 774. " Electrons are atoms of the chemical element electricity ; they possess mass ; they form compounds with other elements ; they are known in the free state, that is, as molecules."

> " From this great deep, before our world begins,
> Where all that was to be in all that was
> Whirl'd for a million aeons thro' the vast
> Waste dawn of multitudinous eddying light."

According to Prof. J. J. Thomson, the elements are supposed to have evolved from this fire-mist in the following manner :—

The vapour was composed of particles both positively and negatively electrified. These attracted each other with very great forces, but the tremendous speed of their motions parted them even as they flashed by each other. Gradually, however, the particles radiated away energy in the form of light and heat, and, as a result, their motion became less and less swift until occasionally permanent connections were formed between them, and the first step in granulation took place. Thus the matter-atoms were formed as the price of the gleaming electrical light which the nebula sent forth ceaselessly.

These first atoms consisted of only a few electrons grouped together, and were consequently much lighter than any elementary atoms now found upon the earth, the lightest of which consist of many thousands of electrons grouped together. Slowly during ages this aggregation of electrons continued, the atoms gradually growing and becoming more and more complex, until finally they consisted of aggregations of over a thousand electrons, and formed the atoms of the element hydrogen ; the lightest atom known to us upon the earth is thus the end-product of a vast epoch of evolution. It represents the gradual condensation of over a thousand electrons. Before hydrogen there came a whole series of lighter elements which have long since vanished from our earth, having condensed into heavier elements. Astronomers say that in some nebulæ, and even in the upper regions of the sun's vast atmosphere, such light unknown elements still gleam and glow. Many nebulæ, indeed, are entirely composed of them.

With the appearance of hydrogen the process of condensation did not cease. All matter still continued passing in a stupendous scheme of slow continuous evolution from the

lighter to the heavier forms. Yet for some time hydrogen was the only element in existence, and even now we often find nebulæ and some very hot stars almost entirely composed of this gas. The amount of hydrogen thus found occasionally collected together in one region of space is almost inconceivably vast. The hydrogen in many a single star would out-weigh the vast mass of our earth a million times and more! But hydrogen did not remain long the only element in existence; the gradual accretion of electrical particles soon caused it to change into other and heavier elements. Elements like magnesium, calcium, iron, carbon, made their appearance, and at the same time the quantity of hydrogen diminished. Thus there was a practically continuous increase of atomic mass from the lightest to the heaviest known atom.

A fairly consistent theory to account for the formation of the elements, founded on the researches of the Curies, Ramsay, Soddy, Rutherford, and others, has recently been put forward by A. C. and A. E. Jessup.*

According to these writers, in the earliest nebulæ—the first stage of matter of which we have any knowledge—there exist only four elements, namely, two still unknown upon the earth, together with hydrogen and helium. These are the four elements from which all the others have formed, and these authors term them "protons" to distinguish them from the other elements. The electrons are supposed to condense about the atoms of these protons in the form of concentric rings; so that in order to imagine the appearance of an atom, we must look upon it as composed of a series of rings of varying sizes, whose particles are in exceedingly rapid motion, and indeed, as we shall see presently, the stability of the rings is a consequence of the rapidity of the motion of the particles of which they are composed. This theory of atomic evolution explains the fact that all the elements are not met with in equal abundance. For the rate of accretion of mass is most rapid between positions of maximum stability as represented by our 70-80 elements. The intermediate forms in the upbuilding process of matter

* *Phil. Mag.*, January, 1908, p. 21.

have never accumulated in sufficient quantity to be detected by direct methods. The stable terrestrial elements represent only stages where the rate of change is slowest; they are, so to speak, stopping-places in the process of evolution. And in general the more slowly an element changes into the next sort the more it will accumulate and tend to become abundant. Thus as the universe gets older and older elements of higher and higher atomic weights appear. Their appearance, however, will not involve the annihilation of the elements of lower atomic weights.* The number of atoms of the latter will, of course, diminish, since they go to furnish the material out of which the heavier elements are built up. But the whole of the light atoms will not be used up at once, and thus a large number of elements, both light and heavy, will exist simultaneously. The lighter elements, however, must ultimately disappear, and unless there is a simultaneous disintegration of the heavier elements, the atomic weight of the lightest element surviving must increase.

We may mention here that the formation of the successive elements is attended by the escape of large quantities of energy, and that the systems are steadily progressing from a higher to a lower energy content. The whole process of evolution is entirely governed by the possibility of energy leaving the system.—(Jessup, *loc. cit.* p. 24.)

This slow, continuous transmutation of the elements, working for many ages, has probably produced stupendous effects upon the earth. The majority of light elements have already disappeared from it, the bulk of the interior being composed of heavy elements. Only on the surface there still lingers a thin skin of light elements, such as oxygen, nitrogen, carbon, hydrogen, silicon,—elements composing the bulk of the air, water, living matter, and rocks. If in the course of ages the light elements become converted entirely into heavy ones, which are usually metallic, the whole earth will become a vast metallic ball having the same composition as one of the iron meteorites which wander in space, and on which the same evolutionary forces have

* J. J. Thomson, "Electricity and Matter" (Constable, 1904).

already been working for ages. The green fields and the rich soft earth which now clothe our planet will vanish, and in their place will stretch a vast, hard, metallic desert, lifeless, waterless, airless, whirling silently in space towards an unknown destination. The merest glance at the sky through a telescope will show us that our world is only one of many worlds, a number of which must have long since reached such a stage of development. One can scarcely doubt, therefore, the general correctness of the poet Tennyson's conjecture that in the myriad-worlded universe about us

> " Many a planet by many a sun may roll
> With the dust of a vanished race,
> Swallowed in Vastness, lost in Silence,
> Drowned in the deeps of a meaningless Past."

And that some day our own world will go to join them, for

> " Many an Aeon moulded Earth
> Before her highest, Man, was born.
> Many an Aeon, too, may pass when
> Earth is manless and forlorn."

" This is very interesting," I seem to hear my readers say, " but how do we know that it is true or even probable ? " It would take too much of our time and space to completely discuss the evidence in favour of these conclusions, and I cannot do better than refer the curious to the pages of Professor J. J. Thomson's books* where a full account will be found by one of the founders of the theory. Also a long series of difficult researches on the spectra of the stars, by Sir Norman Lockyer, affords confirmative evidence of the truth of this theory. Lockyer† shows that while the cooler stars consist principally of elements with heavy atoms, such as iron, calcium, manganese, and nickel, the hotter stars consist principally of elements with light atoms ; and if we arrange the stars in ascending order of temperature, the quantity of the heavier elements steadily diminishes as the temperature increases, and in proportion as they diminish

* See " Electricity and Matter," by Thomson (Constable, 1904). " Recent Developments of Physical Science," by Whetham (Murray, 1905). " The Interpretation of Radium," by Soddy (1910).

† " Inorganic Evolution " (Macmillan, 1900).

their place is taken by the lighter elements, until in the hottest stars of all the heavy elements have completely vanished, such stars being completely composed of the lightest of all known elements, such as the gaseous hydrogen, helium, nebulium, and asterium. The inference is that the heavy atoms have under the reign of enormous temperatures broken down into lighter atoms. In Lockyer's words:

"In the very hottest stars we deal, speaking generally, with the gases hydrogen, helium, asterium, and doubtless others still unknown, almost exclusively. At the next lowest temperatures we find these gases being replaced by metals in the state in which they are observed in our laboratories when the most powerful arc-spark is employed. At a lower temperature still the gases almost disappear entirely and the metals exist in the state produced by the electric arc. . . take iron as an example. . . it will be seen . . . that as the temperature increases hydrogen increases, and, together with the cleveite gases not obvious before, finally replaces the iron which has disappeared. This is one of the great stellar revelations, and it must be remembered that we have now hundreds of photographs which we can bring together to study the gradual change. There are no 'breaks in strata.' One of the most wonderful things about this line of work to my mind is the simplicity, coupled with the continuity of the phenomena. . . it carries conviction with it. We have then to face the fact that on the dissociation hypothesis, as the metals which exist at the temperature of the arc are broken up into finer forms, which I have termed proto-metals, at the fourth stage of heat (that of the high-tension electric spark) which gives us the enhanced spectrum; so the proto-metals are themselves broken up at some temperature which we cannot reach in our laboratories into some other simpler gaseous forms, the cleveite gases, oxygen, nitrogen, and carbon being among them.

"Does the story end here? No, there is still a higher stage; after the cleveite gases have disappeared as the arc lines and enhanced lines did at the lower stages, the new form of hydrogen to which I have before called attention, and which we may think of as 'proto-hydrogen,' makes its appearance. But there are already evidences that this is not the end of the simplifications brought about by the transcendental temperatures we are now discussing."*

In this manner† each nebula and each sun must be regarded as swiftly weaving the vast fabric of the universe at the loom

* Quoted by kind permission of Macmillan & Co. from Lockyer's "Inorganic Evolution," pp. 56 and 81.

† Some chemists of great ability do not accept Lockyer's conclusions. Arrhenius, for example, believes that the fact that nebulæ are composed of light elements like hydrogen, helium, nebulium, etc., can

of time. They are, in fact, the great chemical workshops of the universe in which the elements are forged and fashioned. In them and on a stupendous scale, often at temperatures and pressures so vast as to be almost inconceivable to us, the different kinds of atoms are conceived and born ; and from these atoms the whole order of creation magnificently evolves, sun by sun, world by world, beast by beast, plant by plant, down to the minutest microscopic animalculæ swimming in a drop of water. We must, therefore, now say a few words about these vast stellar laboratories.

How huge some of the nebulæ are may be gathered from the fact that one* of them alone, and that one not the largest by any means, covers an area in the sky about five times that of the full moon, and yet is such a vast distance away as to be practically immeasurable by our most refined and delicate instruments. A minimum estimate of its distance from the sun shows that it must have a diameter at least 500,000 times the sun's distance from the earth ! Light at the velocity of 186,000 miles a second would take more than eight years to pass from one side to the other of this vast nebula ! and yet light moves so quickly that in a single second it will flash 200 times from London to Edinburgh and back again. A better idea, perhaps, of the size of this nebula may be obtained by supposing that a railway were laid across it, and that a train starting on its long journey over this railway was not to stop until it reached the other side of the nebula. Suppose the train went off with the speed of a mile a minute ; then it would travel on hour after hour until slowly the hours would lengthen into days, and the days would creep into years, the years would swell into centuries, and still the train would rush on, day and night, century after century, for

be explained by assuming that under the great cold reigning in such regions of space, all except the lightest elements have condensed to a liquid or solid state, and have gravitated together into the interior regions of the nebula. The shell of gas existing on the edges of the nebulæ is then rendered luminous, and so apparent to us, by dust particles and electrons flying into it from space.—(Arrhenius, "Das Werden der Welten," p. 176.)

* The nebula in Argo, see Gore's "Worlds of Space," Chapter 20.

thousands and tens of thousands and hundreds of thousands of years until a million years had passed. And even now the nebula is not nearly crossed; for the train has barely passed the hundredth part of its journey along the mighty track! Not until the train had rushed on at the unabated speed of a mile a minute for ninety million years would the terminus at the other side of the nebula be reached! It is highly probable that even then it would not be reached, no, not for æons of ages afterwards, for our estimate of the size of the nebula is, remember, a minimum one. This is only one nebula out of thousands upon thousands which can be seen in the sky by means of a small telescope!

That strange unknown changes are going on in these vast gaseous mists is admitted by all who have studied them. "The astronomer finds it difficult," says Simon Newcomb* "to conceive that the great nebulous masses which he sees in the celestial spaces—millions of times larger than the whole solar system, yet so tenuous that they offer not the slightest obstruction to the passage of a ray of light through their whole length—situated in a region of what seems to be eternal cold, below anything that we can produce on the earth's surface, yet radiating light, and with it heat, like an incandescent body—can be made up of the same kind of substance that we have around us on the earth's surface. Who knows but that the radiant property that Becquerel has found in certain forms of matter may be a residuum of some original form of energy which is inherent in great cosmical masses, and has fed our sun during all the ages required by the geologist for the structure of the earth's crusts? It may be that in this phenomenon we have the key to the great riddle of the universe, with which profounder secrets of matter than any we have penetrated will be opened to the eyes of our successors. . . Astronomical and physical research are now being united in a way which is now bringing the infinitely great and the infinitely small into one field of knowledge. Ten years ago the atoms of matter, of which it takes millions of millions to make a drop of water,

* "Side-lights on Astronomy" (1906), pp. 21, 59, by kind permission of Harper and Brothers, the publishers.

were the minutest objects with which science could imagine itself to be concerned. Now a body of experimentalists, prominent among whom stand Professors J. J. Thomson, Becquerel, and Röntgen, have demonstrated the existence of objects so minute that they find their way among the atoms of matter as raindrops do among the buildings of a city. More wonderful yet, it seems likely, though it has not been demonstrated, that these little things, called 'corpuscles,' play an important part in what is going on among the stars. Whether this be true or not, it is certain that there do exist in the universe emanations of some sort, producing visible effects, the investigation of which the nineteenth century has had to bequeath to the twentieth."

If strange changes take place in the nebulæ, still stranger take place in many of the giant suns of space. Here chemical changes progress night and day, century after century, under conditions quite unparalleled and unparallelable in our earthly laboratories. For down in the depths of these giant bodies is a heat immeasurably fiercer than any heat we know upon this earth, and a pressure immeasurably vaster than any pressure that we can imagine.

Some idea of the magnitudes of these stellar temperatures may be obtained by considering the case of our sun, a relatively cool body in comparison with some of the suns of space. Yet its surface actually attains the prodigious temperature of 6,200 C., a temperature high enough to boil steel like water and to instantly convert the most involatile substances known upon the earth into a mass of white-hot vapour. Lockyer estimates that the surface temperature of some suns is at least 30,000 C.! for certain stars radiate out, surface area for surface area, a vastly greater amount of heat and light than does our sun. But even these surface temperatures, great as they seem to us, are quite insignificant when compared with those prevailing hundreds of thousands of miles in the depths of these vast globes. Arrhenius speaks of a temperature of 71,000,000° C. Incredible! you will say. Not a bit of it. For we have seen in our first chapter that matter cannot travel faster than light, and therefore the highest temperature attainable by any

substance will be reached when its molecules travel with the velocity of light, that is, at the rate of 186,000 miles a second. Now it can be calculated easily that when the molecules of hydrogen attain this unheard-of speed the gas will be at the enormous temperature of between six and seven million million degrees centigrade. Such hydrogen would be a hundred thousand times hotter than a star at the temperature mentioned by Arrhenius! Indeed we know that on the sun vapours are hurled about with a speed of over 500 miles a second. If the molecules themselves which make up such vapours possess anything like these average speeds the mean temperature of the vapour itself must amount to several million degrees centigrade.

We can realise easily a degree of heat expressed by the temperature of boiling water; we can even realise, but with some difficulty, a degree of heat half-a-dozen times hotter than this, for example, that of molten iron; * but when we come to deal with temperatures two hundred thousand times hotter than boiling water, our imagination fails us altogether. Now, if a temperature merely 5 to 6 times hotter than boiling water produces such a great difference in the properties of matter as that which exists between the water boiling in our kettles, and the gleaming, dazzling, white-hot molten iron, seen as it pours from the great blast-furnaces of iron works, we may well dimly wonder what would be the effect of a vast stellar temperature 200,000 times hotter! How puny in the face of these tremendous natural temperatures appears the greatest intensity of heat ever produced on the earth by man—that of 7000° C. in the electrical furnace! Is it a wonder that on such stars in their mighty depths chemical changes absolutely unrealisable in our earthly laboratories proceed with the greatest ease?

The words of the dying Victor Meyer rang prophetically in the ears of the chemists of his time: "There can be no doubt," he said, "that new and undreamed of discoveries will manifest themselves, that a new chemistry will disclose

* Water boils at 373° Absolute (100° C.), iron melts at 1873° Absolute (1600° C.). Hence molten iron is about five times hotter than boiling water.

itself, when we are furnished with vessels that will enable us to work at temperatures at which water no longer exists, and at which the oxy-hydrogen blowpipe flame becomes a non-inflammable mixture." Science is rapidly approaching the time when Meyer's dream may perhaps be realised.

Enormous as these stellar temperatures may seem, they are more than paralleled by the stellar pressures. The pressure at the centre of the earth has been estimated at three million atmospheres, or, 20,000 tons per square inch.* Now the earth is a mere speck in comparison with the sun. The sun outweighs the earth three hundred thousand times! Their relative size is expressed by that of a grain of fine shot and a full sized football, or a marble and a full sized living room. The diameter of the sun is 866,400 miles, nearly a hundred times that of the earth (9,718 miles), while its volume is 1,395,000 times that of the earth. "If a million globes," says Sir Robert Ball, "as large as our earth could be united together, no doubt a vast globe would be produced, but it would not be so large as the sun. Think of a single house with three or four people living in it, and then think of this mighty London, with its millions of inhabitants. The house represents the earth, while great London represents the sun!" Now if the pressure 4000 miles down in the interior of the earth is of the order of 20,000 tons per square inch, what would be the pressure at the sun's centre at the vast depth of 400,000 miles? It would seem that there certainly exist suns in space far vaster than our sun. Thus, the star Mizar, the middle star in the tail of the Great Bear, is a double sun weighing forty times as much as our sun. This is quite a small body compared with such giant suns as Capella, Arcturus, Canopus, and Rigel, bodies so far off that their distance is immeasurable by the most refined instrumental means known to astronomy, and yet emitting light with such power as to appear the brightest stars in the heavens. According to Newcomb† the actual amount of light emitted by Canopus

* Geikie's "Text-Book of Geology" (4th edition, 1903), p. 59, Vol. I.

† "Side-lights on Astronomy," p. 397.

and Rigel is certainly thousands, and probably hundreds of thousands of times that emitted by our sun. Such bodies must be extraordinarily massive, probably entirely dwarfing our sun, vast as he seems to us. This is confirmed by measurements made on other stars. Listen for example to what Gore* says about Arcturus :—

"A minute parallax of about one-sixteenth of a second of arc, found for Arcturus by Dr. Elkin, gives a still more astounding result. This small parallax implies a distance from the earth of about twelve millions times the sun's distance. . . . The sun placed at the distance of Arcturus would be reduced to a star of only $9\frac{1}{2}$ magnitude. It would not be visible in an opera glass ! Arcturus is therefore . . . over 6000 times brighter than the sun would be if placed at the same distance. Assuming the same density and brightness as the sun, the diameter of Arcturus would, therefore, be about 79 times the sun's diameter, or over 68,000,000 miles, and its mass about 500,000 times the mass of the sun ; figures well calculated to 'stagger the imagination.' From the small value of the parallax found for Arcturus, we cannot, of course, place very much reliance on its accuracy ; but there can be little doubt that this bright star is really very great, and that consequently it is a much larger sun than ours, probably one of the most massive bodies in the universe."

In the depths of such giant bodies the pressures may amount to millions, perhaps billions, of tons on the square inch. It is, indeed, difficult to imagine such tremendous pressures. At a pressure less than two hundred tons on the square inch the strongest steel will flow like mobile water, and the solid condition of matter loses all meaning. We can only speculate as to how matter will behave when subjected to these vast stellar pressures.

Equally extraordinary are the titanic forces which hurl matter about over the surfaces of these fiery globes. On them explosions occur a thousand times more violent than the mightiest dynamite explosion ever known. White hot winds rush over their surface a thousand times swifter than a rifle bullet, winds which would shatter and tear to pieces in an instant of time our whole earth, vast as it seems to us. We are quite unable to realise such conditions. And yet these are the normal conditions under which chemical

* Gore, "Worlds of Space," pp. 74-75, by kind permission of the Author.

change goes forward in the universe. It seems quite impossible to attain in our earthly laboratories the means to imitate chemical changes which require such enormous temperatures and pressures, changes such as the breakdown of one element into the other, which seems to progress with such ease in the stars, and the unlocking of the titanic energies stored up in the atoms. For our whole world is but a tiny atom flying in a sea of giant suns. It is itself but a tiny product of the vaster stellar laboratories. It is clear, therefore, that human chemistry must, after all, be a very one-sided affair. It is as a rule only concerned with chemical changes which take place under conditions of temperature and pressure not greatly different from those under which we live and work. Our chemistry is, in fact, just one chance section through the vast organism of chemical facts. What wonders would be revealed if we could only take other sections at vastly different temperatures and pressures, and thus enter into the great unknown chemical world which exists under physical conditions totally different from those we are acquainted with, will probably remain for ever veiled from the intellect of man. The wonder is not that we know so little but that we know so much.

For in Tillman's words,* "Above and below the narrow zone of the visible are objects too far off and too fine for human scrutiny. Although the 'seeming all' is rounded by intimations of other and brighter regions, Science can never compass them by any extension of her domain. In those unsounded depths which form the boundary and the background of the known, thought, grown dizzy, finds no support."

Tennyson has expressed the same idea in grand and beautiful language in his "Ancient Sage" in the well-known lines :

> "For Knowledge is the swallow on the lake
> That sees and stirs the surface shadow there
> But never yet hath dipt into the abysm,
> The abysm of all abysms, beneath, within,
> The blue of sky and sea, the green of earth,
> And in the million-millionth of a grain
> Which cleft again for evermore,
> And ever vanishing, never vanishes."

* "Nature," 1872.

We have seen that in the heavens before our eyes there is taking place a swift and ceaseless formation of heavier from lighter elements by a process analogous to condensation; but the reverse process is certainly taking place in parts of the earth; for elements have been recently discovered which are undoubtedly breaking down into lighter elements; thus the element radium appears to give rise to helium, the light gas which exists in so many stars. It has recently been shown that changes of a similar nature are going forward slowly, in many elements, especially in thorium, uranium, and the alkali metals. Such elements are known as "radio-active," on account of peculiar rays which they send out. We will later devote some space to the radio-active elements, and so it must suffice to say that if in certain regions of the universe matter is condensing to heavier and heavier elements, it is equally certain that in other regions the heavy elements are again breaking up into lighter forms of matter. In other words the atoms can be split up into their dust or primary matter, in the same way that comets break up into meteorites, and just as the geological changes of the earth or the building up and dissociation of heavenly bodies proceed incessantly before us, "so also do the atoms break up and form again in the silence of their eternal evolution."

There is nothing surprising in this. The chemical atoms grow out of a fine ultra-atomic gas, in the same way that visible raindrops grow out of invisible aqueous vapour; and the atoms dissolve again into this ultra-atomic mist, just as raindrops evaporate away again into invisible aqueous vapour. There is thus going on a continual mighty change in matter, slow to our eyes but inconceivably swift when measured by the standard of eternal time. Now just as a planetary system will collapse if the velocity of the planets falls below a certain value—the planets then rushing into the central sun round which they revolve—so also in the atoms, if the velocity of rotation of the electrons becomes reduced below a certain critical value, a stable configuration of rotating electrons will become unstable and the atomic planetary system collapses with a crash. When this occurs the tiny fragments fly in all directions, some being shot out

with a velocity of a hundred thousand miles a second! The residue of whirling corpuscles again group themselves into another configuration which is stable under the altered conditions. A new element is thus formed. After some time this, losing energy, becomes unstable and in its turn forms another atomic species with the loss of some more electrons.

These changes have been most carefully studied in the case of the newly discovered element radium, which breaks down into several products, among which is the light element helium. Each change is usually attended with the evolution of electrons, and proceeds so rapidly that according to Rutherford* half a given mass of it is destroyed every 1,300 years. It has recently been shown that almost all the elements eject corpuscles, after the manner of radium, and hence are probably undergoing a very slow decomposition.

The amount of energy set free by the decomposition of these atomic systems is incredibly vast. Thomson has calculated that if the energy in the atoms of one gram (*i.e.*, 15½ grains) of hydrogen was liberated it would be able to lift a million tons to a height considerably greater than a hundred yards!

One ton of radium in decomposing gives out enough heat in one hour to raise the temperature of one ton of water to its boiling point. Hour after hour, year after year, it continues to do this, and would continue to do so until, some thousands of years hence, it had exhausted its store of energy. And thus it is that men came to realise that within the very atoms of matter there exists such incalculably vast funds of energy that the sum total of all the energies previously recognised, and now called extra-atomic, are as nothing compared to them. "This is a change, indeed," says Dr. Saleeby, "that all the energies hitherto known to us should be merely the overflow trickling from the immeasurable ocean of intra-atomic energy."†

Before the advent of radium the whole universe was

* Rutherford, "Radio-activity" (Cambridge, 1905), p. 450.

† "Harmsworth's History of the World," Vol. I.

supposed to be hastening into a state of death. Universal gravitation was supposed to be slowly collecting together all matter into one great heap, and outside of the aggregation of suns which form our universe there existed nothing but empty space extending for all infinity. All the suns which thus form our limited universe were known to be radiating away their heat and light, and thus all must cool and the universe must end in the death of an everlasting cold and night. This comfortless doctrine did not appeal to every one. The great thinker, Herbert Spencer, asserted that there must be some unknown forces at work which opposed the obvious tendency of matter to aggregate into a state of death. There must be disintegration going on as well as integration. He believed that the universe was eternal; that it had always existed and always would exist in a state of never-ending change.

Spencer was ridiculed by many eminent physicists, and at his death one of the greatest thinkers that England has ever produced was not thought worthy of a burial place in Westminster Abbey. Recent discoveries, however, seem to indicate that Spencer was considerably nearer the mark than his antagonists. Radium shows that there is going on a continual breakdown of integrated matter into lighter forms, while astronomical observations indicate that at the same time there is going on an upbuilding of heavy from light elements. Thus apparently there is going on in Spencer's sense a continual circulation of matter in the universe, a vast cycle of change from light to heavy and heavy to light.

It is true that the formation of heavy from light elements in incandescent masses of matter like the stars is probably a comparatively speaking, rapid process, while the break down of integrated into disintegrated matter, as it occurs on our earth, and in other cold non-luminous masses of matter, is probably a fairly slow process. A single pound of our ordinary matter will probably exist for many billions of years. Yet when we come to consider that the mass of dark invisible matter in the universe probably is a million times greater than the quantity of incandescent matter, the slower rate of disintegration of the cold matter is com-

pensated by the very great masses of matter thus simultaneously disintegrating; and thus the rate of formation and the rate of disintegration in the long run balance each other.

We have still to face the problem of the continual radiation of heat and light into space. This has always seemed a great waste to many scientists, who could hardly bring themselves to believe that it was really lost. This objection has been well put by Newcomb. "What," says he, "becomes of the great flood of heat and light which the stars radiate into empty space with a velocity of one hundred and eighty thousand miles a second? Only a very small fraction of this can be received by the planets or by other stars, because these are mere points compared with their distance from us. Taking the teachings of our science just as it stands, we should say that all this heat continued to move on through infinite space for ever. In a few thousand years it reaches the confines of our great universe. But we know of no reason why it should stop here. During the hundreds of millions of years since all our stars began to shine, has the first ray of light and heat kept on through space at the rate of one hundred and eighty thousand miles a second, and will it continue to go on for ages to come? If so, think of its distance now, and think of it still going on to be forever wasted! Rather say that the problem what becomes of it is as yet unsolved."

Now it has been shown recently that radiant light and heat exert a pressure on very light particles of matter, repelling them into the depths of space, away from the great suns which give out heat and light. These dust particles gradually accumulate in the depths of the universe away from large masses of matter, and form vast nebulæ, which after ages condense to suns and worlds again. Thus the light and heat is not wasted, it is all caught in the infinite depths of space by innumerable grains of dust, and thus forms an important part in the formation of new worlds. These worlds ultimately collide with the dark, cold, burnt-out suns, which rush, apparently so aimlessly, through space, and by the appalling force of the collision again reproduce nebulæ, which again condense to worlds. And so on for all the ages circulates

the universe, like some vast self-compensating machine, radiation pressure compensating gravitation, and the concentration of potential heat energy in the nebulæ compensating its loss in the suns. Thus, although the earth will pass away, and with it Man and the very elements of which he is composed, we have no reason to believe that the universe itself will ever end by sinking into that state of death foretold by the physicists of the last century. The probabilities are that life exists and always will exist generally disseminated through it wherever the conditions are favourable; and that although life may come to an end in one planet yet there are always other planets where it can continue to flourish.*

All this has been expressed by Sir Lewis Morris in the following beautiful words:

"Undying is each cosmic force:
Undying, but transformed, it runs its endless course.
It cannot wane, or sink, or be no more.
Not even the dust and lime which clothe us round
Lose their own substance in the charnel ground,
Or carried far upon the weltering wind;
Only with other growths combined,
In some new whole they are for ever—
They are and perish never.
The great suns shed themselves in heat and light
On the vast vacant interstellar air,
Till when their scattered elements unite
They are replenished as before they were.
Nothing is lost, nor can be: change alone,
Unceasing, neverdone,
Shapes all the forms of things, and keeps them still
Obedient to the Unknown Perfect Will."†

* A full discussion on the possibility of life existing on other planets under physical conditions widely different from those now holding on the earth will be found in the author's work, "Researches on the Affinities of the Elements" (Churchill, 1905), Appendix B, pp. 245-257.

Arrhenius ("Das Werden der Welten," Chapter 7) discusses the possibility of germs of life being driven from world to world by means of the repelling force of radiation pressure.

† By permission of Kegan Paul, Trench, Trübner & Co., from "The Wanderer."

CHAPTER IV

THE WONDERS OF CHEMICAL CHANGE

THE importance of chemical change to mankind can scarcely be realised by any one not acquainted with chemistry. The fires which burn in our grates and supply us with warmth and light during the cold and gloomy winter months, the explosion which hurls a bullet with irresistible force from a rifle barrel, or which blasts up great rocks in our quarries, the power which drives our locomotives and steamships far over land and sea, are all due to chemical changes. The simplest as well as the most complicated changes which accompany life are, to a great extent, chemical in character. We cannot cook our dinner, nor digest it when cooked, we cannot move, laugh, or talk except by the direct operation of chemical changes. Even the very thoughts which flash so quickly through our minds, and the passions which stir us to love or hate, are inseparately connected with chemical changes that take place in our brains. In order to be convinced that vital changes are closely connected with chemical phenomena, we need only to observe that the higher breathing animals resemble the burning candle not only in producing the same products of combustion, viz.—water and carbon dioxide, but also in the heat they produce; for animals, like flames, are hotter than the surrounding air, and the difference between them is one of degree only. In the candle the oxidation goes on quickly and is confined to one spot—the wick, whereas in the case of an animal oxidation goes on slowly and takes place throughout the body. The poet who first compared life to a flame was nearer the truth than perchance he imagined.

We have not yet explained what we mean by a chemical change. A chemical change is brought about by atoms of different sorts rushing together, or "combining," as a

chemist would say, to produce new substances. Thus, if powdered sulphur and fine copper filings are well mixed, a green-coloured powder results, in which, however, a microscope will show the particles of sulphur lying by the side of the particles of copper. On gently warming this green powder it suddenly bursts into bright incandescence, and, on cooling, a uniform black mass is produced. This is neither copper nor sulphur, but a chemical compound of the two, in which no particles of either of the substances can be seen, no matter how high a magnifying power be employed, but from which, by the employment of suitable chemical means, both copper and sulphur can be extracted. What has happened? The atoms of copper and sulphur have combined, causing while so doing such an atomic agitation that heat and light are evolved, and as a result a body is produced quite different from either copper or sulphur, yet composed of atoms of sulphur and copper united.

A scene from a ball-room will illustrate this rearrangement of atoms. At one end of the brilliantly lighted hall stand a number of men, confusedly grouped together and talking. We take them as representing the copper atoms before union. Similarly at the other end of the room is a group of gaily dressed and animated ladies. These we take as representing the sulphur atoms. Though occasionally a man moves or a girl laughs there is little movement among the mass of people, and the whole scene corresponds to the, comparatively speaking, quiescent mixture of sulphur and copper atoms before chemical union. Suddenly the music commences for a dance. All is instantly in a state of motion. The men come hurrying up to the ladies, each bent on securing a partner, and in a few seconds the whole assembly rearranges itself and goes dancing away in pairs. The confused rush of the men for the women corresponds to the moment of chemical union of our copper and sulphur atoms; the increased motion stirring in the people at this time representing the rapid molecular agitation attending chemical union, which usually manifests itself as heat and light. Finally the new arrangement of the assembly into pairs, each consisting of a man and woman, corresponds to the

new arrangement of the copper and sulphur atoms in the black copper sulphide produced as the result of chemical combination.

What occurs in this reaction between copper and sulphur is typical of chemical change in general. In each case we get a set of atoms uniting or separating, and the moment of union or separation is marked by a thermal disturbance of some sort, this thermal disturbance taking the form sometimes of a sudden evolution of heat and light, but sometimes of an absorption of heat ; but in all cases of chemical union the products of the change differ entirely in appearance and properties from the bodies producing them.

Naturally the question which next presents itself to the mind of the reader is this : What causes the atoms to unite ? The answer to this question is that the atoms unite in consequence of attractive forces they exert on each other. These forces, however, cannot be due to the same gravitational force that urge planets and suns together. They are far too vast for that. The chemical forces of the atoms exceed the gravitational forces which such small masses exert, not millions but billions of times, as Helmholtz showed many years ago. Besides, the chemical forces are selective, while gravitational forces are not. The atoms, in fact, are dreadful snobs and are most particular with whom they associate. For example, fluorine atoms have a great attraction for hydrogen atoms and combine with them at ordinary temperatures so fiercely as to produce flame and even explosion ; but these fluorine atoms will have nothing whatever to do with oxygen atoms, which are much more chemically active than hydrogen atoms. They cannot be made to combine with them at all. The same sort of thing occurs with the atoms of all the eighty odd known elements ; but little is known at present regarding the mutual attraction of the atoms for each other, and no doubt in this field many of the greatest discoveries of the future will be made.* The subject, in fact, is in its infancy.

* The reader will find collected together nearly all that is known regarding the mutual attractions of the atoms for each other in the author's work, " Researches on the Affinities of the Elements and on the Causes which determine the Chemical Similarity of Elements and Compounds " (Churchill, 1905).

The idea which prevails at present in the minds of chemists and physicists is that these chemical forces are due in some way to electrical charges associated with the atoms. Certainly the incredible vastness of some of these chemical forces is well explained by this assumption. For example, d'Albe* calculates that two grams of pure negative electricity placed side by side at a distance of one centimetre will repel each other with a force of over 320 quadrillion tons! Even if they were placed one at the North Pole and the other at the South Pole of the earth, they would still repel each other with a force of 192 million tons, and this in spite of the fact that the force decreases with the square of the distance. So that a very small electrical charge associated with each atom would be sufficient to account for the chemical forces it exerts. The reader, however, must be warned not to accept blindly as true this view, as there exist many phenomena attending chemical combination which are hard to explain on the assumption that the chemical attractive forces are entirely electrical in origin.

The best method of realising the magnitude of these chemical forces is by means of experiment. If the two invisible gases, hydrogen and oxygen, be mixed in a strong glass bottle in the ratio of two volumes of the former to one of the latter, and the mixture be brought near a flame, a bright flash of light and a deafening explosion announces to us that chemical union has taken place. What has been the occasion of the development of such tremendous energy? The formation of a single drop of water, so small that one can hold it on the point of a needle! Water, in fact, is formed by the chemical union of 1800 times its volume of these two gases. And the amount of energy produced in the formation of a single pound of it is adequate to raise 5,300,000 pounds one foot high, or hurl a man of average weight into the air to the height of over seven miles! Who would have believed that such power was concealed in the familiar liquid so intimately connected with our daily life?

The reason why both heat and light are produced by this union of hydrogen and oxygen to form water, whose mole-

* "The Electron Theory," by Fournier d'Albe (1906).

cules are composed of two atoms of hydrogen united with one atom of oxygen, is well worthy of a little further consideration.

Suppose we place an oxygen atom at a small distance from a pair of hydrogen atoms and let us imagine that the atoms are in a fit condition for reacting chemically. These atoms exert mighty chemical forces on each other and instantly begin to rush together. The closer they get the more powerful become the attractive forces and the swifter the atoms fly until they meet with an immense velocity, usually not directly colliding but grazing each other like comets grazing the sun. The final velocities with which the hydrogen atoms meet the oxygen atoms are often over four miles a second! The atoms then commence to revolve one round the other and thus a molecule of water is born. Of course the impulse of the rush carries the atoms far beyond their mean position of equilibrium, and consequently violent surgings backwards and forwards—like the swingings of a pendulum—occur in the tiny new-born molecular system. Since millions upon millions of atoms of oxygen thus unite simultaneously in this way with twice their number of hydrogen atoms, it is obvious that the previously slow-moving mixture of molecules suddenly becomes converted into a mass of swiftly moving molecules. In consequence of this the temperature of the gas becomes enormously raised, because the temperature of a gas depends upon the velocity of the molecules which compose it, increasing, indeed, with the square of the mean gaseous velocity. So that if we double the speed of the molecules we raise its absolute temperature to four times its previous value. In the case of a mixture of hydrogen and oxygen the temperature may, by the act of union, be raised in a few seconds from 0° C. to over 2,000° C.!

We can thus understand easily the generation of a very large amount of heat by means of chemical combination, but something more is required to explain the light. For heat alone will not make a gas luminous. Some of the hottest gaseous flames are non-luminous and almost invisible, while in some chemical reactions in which the heating effect is small the radiation of light is often very powerful. The

evolution of light in a chemical reaction is now thought to be due to some process such as that we describe below.

As we have already explained in our first chapter, light merely consists of the rapid quiverings of a material called ether which fills all space. These quiverings are caused by the rapid rushing to and fro around their orbits in the matter atoms of tiny electric particles called electrons, which revolve like so many little moons around the atoms. Now, as the molecules rush together in the act of chemical combination the electrons on the atoms themselves are violently agitated by the rising and falling attractions of the atoms as they rush past, and are thus set swinging or oscillating violently, so violently, indeed, that we have reason to believe that they sometimes fly off clear from the atom that they were accompanying on its journey through space. Thus the collisions with the atoms of other molecules enormously increases the energy with which the electrons revolve around the atoms, and causes each combining atom to become the centre of these tiny quiverings called light. Millions of atoms in the act of chemically combining each send forth its tiny flash of light, and the united gleam thus produced appears to us as a lightning flash of flame. What unthinkable complexity thus resides in a flame! In the millionth part of a second the electrons must have flashed between one and three thousand million times around the atoms, before they could produce visible light; and this swift motion has been going on in millions upon millions of atoms simultaneously in the tiniest flame that we can perceive!

The whole reaction has taken only the fraction of a second to complete itself. Short as this time is to us, yet it represents to an atom an eternity of time within which vast multitudes of atomic events are capable of occurring, of slowly growing into prominence, and then gradually dying out again.* For example, we can calculate from the kinetic

* Dr. Johnstone Stoney (*Philosophical Magazine*, 1868, p. 132, Vol. 36), illustrates the swiftness of the events going on within the atoms as follows: "The double vibrations of visible light are executed in periods of time which range from 1.3 to 2.6×10^{-15}

theory of gases that within a single second an atom of hydrogen would have ample time to revolve three million million times about an atom of oxygen in the water molecule. Calling familiarly the time of revolution an "atomic year" we see that a single second of our time is worth three billion of atomic years! So that if the above reaction between hydrogen and oxygen gases took only the one-thousandth part of a second to complete itself, nevertheless this time represents a vast interval of 3000 million atomic years! If we, for the sake of illustration, imagined that the water molecules were inhabited and that the time it took an atom of hydrogen to revolve around an atom of oxygen in this molecule bore to these inhabitants the same relationship that the time the earth takes to travel around the sun bears to us, the atomic inhabitants would be quite unaware of the molecular catastrophe proceeding so swiftly about them! The stellar heavens above us may, for all we know, be the theatre of a similar swift change which may complete itself in a few billion years. Yet so vast is this period of time

seconds . . . these swift little motions of light are accordingly related to a 10^{-15} second in somewhat the same way that the motions of our limbs are to a second of time. Now 10^{-15} second is the same portion of a second as a second is of upwards thirty millions of years. Hence the motions of light bear the same relation to one second of time which the motion of our limbs bear to that almost inconceivable cosmical period—a vast succession of geological ages, during which several races of animals, culminating in man, have appeared, have lasted long, and have finally perished from our globe. . . . If there were sentient beings with bodies which move as deftly as this ether, and with thoughts and perceptions as quick as their bodies are active, there would be sufficient time for them within a small fragment of one second to live the lives of all the generations of men that have dwelt upon this earth, thinking all their thoughts and doing all their acts. The mind is almost carried beyond itself in the contemplation of such periods. It is from the vastness of one second in reference to light, that with its little waves light can travel such an immense distance as 298 millions of metres (186,000 miles) in that period of time. It puts a strain upon the mind to form a conception of the mere moment of time that suffices for the light of a candle, at this unheard of pace, to travel one hand breadth from the flame; but brief as this instant is, it corresponds to what several weeks would be in reference to our movements. The light has had time to execute hundreds of thousands of its tiny vibrations."

that the changes now proceeding seem immeasurably slow to us. In the eyes of a being, however, to whom a billion years seem but a second, or in whom a sense of time is non-existent, the whole mighty universe might appear to be in the throes of a swift catastrophe which completes itself instantly! Man, with his empires and cities, would, to such a being, seem but a momentary excrescence, appearing suddenly in the never-ending abyss of time and then vanishing for ever.*

The subject of molecular collision has been discussed very fully by Dr. Johnstone Stoney in the *Philosophical Magazine* (1868, Vol. 36, p. 132, and 1895, Vol. 40, p. 362). Some of his remarks are well worth repeating:

". . in ordinary air about us each molecule meets with something like a million of encounters in something like the seventh part of $\frac{1}{1000}$th of a second. . . the mean length of the path which a molecule of a gas like air passes through before meeting with another molecule is 7×10^{-6} cms. (about the three-millionth part of an inch). The mean duration of each of its little rectilinear excursions is about 1.4×10^{-12} second (*i.e.* something like one and a half times the million millionth part of a second). This fragment of time, tiny as it is, is nevertheless more than 50,000 times the vastly shorter period which suffices for a double vibration of red light, and 100,000 times the duration of a double vibration of the extreme violet ray. And as the periods of the motions which give rise to visible light must lie between these limits, we are forced to conclude that, on the average, something like fifty to a hundred thousand of these little orbital motions are executed (by the atoms) between two consecutive collisions. It is now no longer surprising that the temporary perturbation caused while two molecules are whirling past each other has, in many cases, had abundant time to pass away early in the interval between the two collisions, so as to leave the greater part of the minuter internal motions to be executed in the undisturbed manner

* In this connection it is interesting to note that Prof. Kapteyn and Mr. Edington have shown recently that two mighty streams of stars flowing in opposite directions through space, meet, forming two great intervening universes, which link into each other and pass. That stars often collide in space is a fact well known to astronomers, such collisions resulting in the formation of the nebulæ and the new stars which flash into brightness in the heavens from time to time. The possibility that in the heavens there is taking place a reaction similar to a chemical reaction in which suns and worlds take the part of atoms has gained in probability from the astro-physical researches of the last few years.

which the definiteness of the spectral lines attest to us. We also come to see how the motions with which the molecules dart about amongst one another cannot produce or intercept light; in fact, they are far too sluggish—just as the motions of our fingers, or a very gentle waving of our hand do not produce sound.

"An excellent way of helping to appreciate the events with which we have to deal in molecular physics, is to conceive a model of them in which the durations shall be enlarged all 600 billions of times. If prolonged to this extent, the most rapidly occurring motions in nature that are as yet known to us, viz., those periodic events in a gas which give rise to the lines in its spectrum, would swing at rates comparable with the motions of the limbs of animals, and would then have about as great a range from the swiftest to the slowest. On the same immense time scale the duration of the journeys of the molecules of ordinary air would average about one day each, while the encounter (with another molecule) may last twenty minutes. The motions of the limbs of animals are able to accomplish a good deal in a struggle lasting twenty minutes. On the same scale, the ten-thousandth of a second grows to be of immense duration, extending to 1900 years. The number of struggles (molecular collisions) to be encountered by each molecule in the ten-thousandth part of a second is, accordingly, the same as the number of days in the whole Christian Era, from the birth of Christ down to the end of the present century. If something can be done during the twenty minutes that one of the struggles may last, how great a task may be accomplished by such an enormous succession of them. It must be borne in mind, too, that these encounters are not mere repetitions of each other, but that each has its own definite incidents. Moreover, all this is what occurs in the experience of one individual molecule, so that we must multiply it by a thousand millions, in order to sum up all that may be accomplished by all the encounters of all the molecules within a cubic micron (a cube whose side is $\frac{1}{1000}$ th of a millimetre. There are seventy or eighty cubic microns in the volume of each of the small discs in human blood) of gas in the ten-thousandth part of a second, and that we may in some degree understand how it comes to pass that opportunity is afforded in nature for accomplishing work which requires rare collocations of conditions that can but seldom emerge.

"Such is Nature's real laboratory—events in inconceivable numbers, the whole phantasmagoria of these innumerable events changing every instant down to its minutest details with inconceivable rapidity, the changes in most cases keeping within limits, but in some cases exploring every part of a wide range; it is thus that those wonderful operations are carried on, which issue in the astonishing results that lie everywhere in such profusion around us. We seem almost to get an obscure and partial glimpse of how, in organic nature, tasks of the most unlikely kind are accomplished, through the needful opportunities now and then turning up within each tiny speck of so

Protean a material as protoplasm, a body of which the mutations have probably time relations of the same order as those we have been endeavouring to illustrate, and whose activities are therefore more incessant, more various, and more complex, within every thousandth of a second, in every speck and corner of each living cell, than the mind can even conceive. It is very little man yet knows of what is going on abundantly about him in every stick and stone."

With such wonderful facts facing us on every side it is madness to assert that the progress of Science means the destruction of the spirit of reverence and of wonder. To such criticisms Science may proudly reply in the words of the Earth-Spirit of Goethe's "Faust":

"At the whirring loom of Time unawed,
I weave the living garment of the Lord."

Indeed, owing to the advances of Science, how much more wonderful a world we live in than that of Milton or Shakespeare? How dwarfed the mental vision of all who lived only a few hundred years ago appears to us now! Where our predecessors saw but gleams of light and shade, we see billions of ethereal vibrations flashing swifter than eye or brain can follow. Where they saw grey walls and gentle breezes, we see myriads of atoms and all the wonders of the atomic universe streaming and flaring about us. Truly, every fresh advance of science makes us only more forcibly realise the truth of Minshull's words:

"Land, Sea, and Sky! What mystery and what wonder
Lie hidden in the old familiar sound!
From surging wave and roll of mighty thunder
To the white daisy nestling on the ground."

The chemical forces which drive the atoms into motion have for us an interest which is personal and almost tragic. For men and women, as well as all other living creatures, are but everchanging, evershifting, swarms of atoms which are driven along their endless dance of change by these same chemical forces. Every human deed, every mechanical action of wind, fire or water, is directly or indirectly caused by them. The light-hearted laughter of a young girl, the quick glance of her eyes, the lithe movements of her limbs are, just as much as the tottering movements of an old man or the cry of a child or the gallop of a horse, purely

mechanical effects due to the swift rush of millions of tiny atoms suddenly and irresistibly urged together or apart by mighty chemical forces released in a moment by the action of the will! These chemical forces build up, atom by atom, a thing of life and beauty, such as a flower, a bird, a woman, from a heap of dust, water, and gas, and then as the years roll on they undo their work again, and cause young leaves to grow old and wither and bright eyes to grow dim and strong bodies to grow stiff and feeble and die. Then, wonder of wonders, they convert that which was, perhaps, a brilliantly hued bird flitting in a tropical grove, or a merry sweet-faced maiden singing blithely in the sun, into the gases, water, and dust which surrounds us now!

Who can say what millions of lives the rain-drops splashing in our face, or the dust clouds rolling down the road, have entered into at some time or other of their career? What tales of hope and fear, of joy and sorrow, of times and races vanished thousands of years ago, they could unfold if we could make them relate their history to us! Chemical forces, therefore, reign supreme, not only on this world, but also throughout the stupendous universe of worlds and suns, which indeed are merely vast collections of atoms. For all actions, all events occurring in space and time are but the results of the forces exerted by one swarm of atoms on other swarms.

In Elgar's wonderful version of the old Norse legend of King Olaf, the great war-god Thor is made to declare that:

> "Force rules the world still,
> Has ruled it, shall rule it;
> Meekness is weakness,
> Strength is triumphant,
> Over the whole Earth
> Still it is Thor's Day!"

If Thor's words are made to apply to chemical force I do not think that Science will dispute the correctness of his dictum. Sir Lewis Morris has in our own time beautifully expressed the same idea in the words:

> "There is no God but Force,
> Which, working always on its destined course,
> Speeds on its way and knows no thought of change."

To master the symbolical language of chemistry, so as to understand fully what it expresses, is a great step towards mastering the science itself. We will therefore now explain the use of symbols for expressing chemical changes. To each element we give a symbol, usually the first letter of the Latin name, which is often also that of the English name. Thus O stands for oxygen, H for hydrogen, S for sulphur, Cu for copper (cuprum), Ag for silver (Argentum). These letters signify more than that a particular substance takes part in the reaction. They indicate that element is present in the quantity by weight which is expressed by its atomic weight. Thus O does not stand for any quantity of oxygen, but for one atomic weight, *i.e.*, 16 parts by weight. (See table of atomic weights in chapter III.) H always stands for one atomic weight, *i.e.*, 1 part by weight of hydrogen; and in like manner S, Cu, and Ag stand invariably for the atomic weights 32, 63, and 108 respectively, of these elements.

By placing the symbols of elements side by side a combination of elements is signified, thus:

HCl (hydrochloric acid) represents a molecule consisting of one atom of hydrogen weighing one, united with one atom of chlorine weighing 35.5, the combined weights standing for $1 + 35.5 = 36.5$ parts of hydrochloric acid.

CuO (copper oxide) represents a molecule consisting of one atom of copper weighing 63 united with one atom of oxygen weighing 16, the whole weighing $63 + 16 = 79$. CuO, therefore, stands for 79 parts of copper oxide. Atoms of the same element may unite together: thus, H-H and O-O (or as they are more usually written, H_2 and O_2) stand, respectively, for one molecule of hydrogen and oxygen gas, each molecule consisting of two atoms united together, the molecule of hydrogen weighing 2 and that of oxygen 2×16 or 32. If the molecule contains more than one atom of any element, this is indicated by placing a small number below the symbol of the element. Thus H_2O signifies that this molecule contains two atoms of hydrogen or two parts, united with one atom of oxygen or 16 parts, the whole making up $2 + 16 = 18$ parts by weight of water.

Again $CaCO_3$ (calcium carbonate or chalk) represents a molecule consisting of one atom of calcium, weighing 40, united with one atom of carbon weighing 12, and three atoms of oxygen each weighing 16. So that $CaCO_3$ represents $40+12+16+16+16=100$ parts of chalk.

Let us now illustrate the utility of these chemical symbols for expressing chemical changes. If we throw a pinch of chalk dust into hydrochloric acid, we see a momentary effervescence, which passes and leaves the acid apparently much as it was. No striking outward phenomena have occurred to awaken our surprise or challenge our attention. Yet in this instant of time a wonderful change has taken place. Nothing less, indeed, than the destruction, swift and terrible, of a whole atomic universe. The chalk as it falls into the acid represents the intrusion of one vast stream of whirling atomic systems into another equally vast stream. In an instant millions upon millions of chalk molecules are colliding with equally vast numbers of hydrochloric acid molecules. Each time a molecule of chalk encounters a molecule of hydrochloric acid, both tiny atomic systems are irretrievably shattered and their fragments rearrange themselves into other atomic systems. The slight effervescence noticed marks the swift rush of one series of these rearranged atoms, in the form of a colourless gas called carbon dioxide, whose molecules consist of two atoms of oxygen whirling round one atom of carbon. Water molecules and calcium chloride molecules are similarly born, and go whirling off among the mass of molecules which constitute the hydrochloric acid. Thus an event, one of innumerable other similar events taking place ceaselessly around us, apparently so insignificant as to scarce merit our attention, really represents a stupendous catastrophe in the atomic universe. At first sight it would seem incredible that all the bewildering complexity and intricate detail which necessarily attends the collision of billions of atomic systems, each collision being accompanied by its own train of events which distinguishes it from all the others, could ever be simply and concisely expressed by chemists. Yet chemists, by means of their symbolical language, not only do this, but

they actually express the final result quantitatively! In order to do this the chemical formulæ of the materials taking part in the reaction are placed side by side on one side of an equation, and the products formed as the result of their collision are placed on the other side. Thus in expressing the action of hydrochloric acid upon chalk all that a chemist would say is that the hydrochloric acid decomposes the chalk, giving rise to the colourless gas, carbon dioxide, and the white solid calcium chloride, and the liquid water. And he would represent it by the following equation :*

$CaCO_3$	+	$2HCl$	=	$CaCl_2$	+	H_2O	+	CO_2
Chalk		Hydrochloric Acid		Calcium Chloride		Water		Carbon Dioxide
$40 + 12 + 3 + 16$		$2\ (1 + 35{\cdot}5)$		$40 + 2 \times 35{\cdot}5$		$2 + 16$		$12 + 2 \times 16$
100 parts		73 parts		111 parts		18 parts		44 parts

The sign = is used since the weight of the products on the left hand side is equal to the weight of the products on the right hand side, a necessary consequence of the indestructibility of matter (Chapter I.). The sign + connects the products and signifies " together with." The equation is an expression of the fact that 100 parts of chalk (Ca = 40, C = 12, $O_3 = 3 \times 16 = 48$ and $40 + 12 + 48 = 100$) unite with 73 parts of hydrochloric acid (H = 1, Cl = 35.5, and $HCl = 1 + 35.5 = 36.5$ and $2HCl = 73$) to produce 111 parts of calcium chloride (Ca = 40, $Cl_2 = 2 \times 35.5 = 71$, and hence $CaCl_2 = 40 + 71 = 111$) and 44 parts of carbon dioxide (C = 12, $O_2 = 2 \times 16 = 32$, hence $12 + 32 = 44$) and 18 parts of water ($H_2 = 2$, $O = 16$, $H_2O = 2 + 16 = 18$).

Hence it is clear that the quantity of any one of the products obtained from a given weight of chalk can be easily ascertained by a simple calculation, and that the above equation is a quantitative expression of this change. Every chemical equation used throughout this book is, therefore,

* An account of the ionic theory of chemical change would in these earlier chapters merely confuse the beginner. We will therefore content ourselves by here remarking that in solution it is probable that the molecules break up into electrically charged parts called " ions " and that it is these " ions " which chemically interact, not the undecomposed molecules.

a very wonderful thing. It represents the quantitative results of a number of atomic collisions repeated millions of times over. It is the telegraphic announcement in chemical language that a series of atomic universes have been destroyed by collision and that others have been built up out of their ruins.

The reader is now ripe for a glimpse of one of the most marvellous achievements of modern science in the region of the invisible underworld of atoms. Indeed, so incredible are some of her successes in this direction that the reader may at first be tempted to think that

> "Blinded by some keen too-vivid gleam
> Of the unseen"

science has strayed from the paths of fact into those of fancy.

We know that a molecule is a small collection of atoms so diminutive in bulk that the whole structure is less than the $\frac{1}{25000000}$ of an inch in diameter and consequently far below the limits of anything that we can see in the very best microscope. Yet Science claims that she has not only succeeded in ascertaining that each molecule has a definite structure, but that she knows many of the details of that structure. She knows not only the number of atoms in the molecule, but also how they are arranged or grouped together! Indeed almost all the great chemists of the world are at the present time engaged in investigating this very problem, and what is more, they have, in many cases, succeeded in solving it. We have reached as much certainty in regard to the grouping of the atoms in the molecules of a very large number of substances, as we have in regard to any phenomena beyond the direct reach of our senses. This is a feat of the same order as placing an ordinary watch 75,000 miles away, say between nine and ten times the distance of New Zealand from London, and then ascertaining at this distance the number of wheels it contains, and how these wheels are arranged within it! If a friend held up a watch at a distance nearly a mile from us, how few of us could see it, much less say how it was constructed! How then have these wonders

been achieved? In the simplest way in the world. By merely studying all the changes which a substance will undergo.

Let us illustrate this by the case of sulphuric acid, a substance whose chemical formula is H_2SO_4. In other words it contains two atoms of hydrogen united to one atom of sulphur and four atoms of oxygen. If we drop a metal into a dilute solution of this acid we get off all its hydrogen, thus:

$$\underset{\text{Sulphuric Acid}}{H_2SO_4} + \underset{\text{Zinc}}{Zn} = \underset{\text{Zinc Sulphate}}{ZnSO_4} + \underset{\text{Hydrogen}}{H_2}$$

Hence we can remove all the hydrogen from the molecule without removing its oxygen; but we cannot remove the oxygen without simultaneously removing the hydrogen atoms as well. This shows that the hydrogen atoms are directly joined up to the oxygen atoms. The removal of the two oxygen atoms and with them the two hydrogen atoms may be achieved by adding phosphorus pentachloride, PCl_5, to the sulphuric acid, thus:

$$\underset{\text{Sulphuric Acid}}{\begin{matrix}HO\\HO\end{matrix}\!>\!SO_2} + \underset{\text{Phosphorus Pentachloride}}{PCl_5} = \underset{\text{Sulphonyl Dichloride}}{\begin{matrix}Cl\\Cl\end{matrix}\!>\!SO_2} + \underset{\text{Phosphorus Oxychloride}}{POCl_3} + \underset{\text{Water}}{H_2O}$$

Hence we must write the sulphuric acid molecule as follows:

$$\begin{matrix}H—O\\H—O\end{matrix}\!>\!SO_2$$

The lines connecting the atoms show how the atoms are linked together. This constitution clearly explains why we can remove hydrogen atoms without removing oxygen, and why we cannot remove two of the oxygen atoms without simultaneously removing the hydrogen. The two remaining oxygen atoms are very intimately bound up with the sulphur atom and cannot be easily removed. The molecule thus pictured is a system in motion. It is in its way a sort of tiny planetary system with the atoms whirling round with very great speeds. Yet the crude formula of the chemist depicts it as a system in a state of supreme repose. Let us

try, therefore, if we cannot read into the stiff lines of the constitutional formula some kinetic interpretation.

Let us first consider the case of a system like the earth and moon. Here the moon revolves round the earth and accompanies it on its journey through space. The moon is thus in chemical language "linked up" to the earth, and a chemist would express this relationship by a "constitutional formula" like this:

M—E

where E stands for the earth and M for the moon.

Now is this not exactly analogous to the constitutional formula of a simple molecule like that of hydrochoric acid or copper oxide which are expressed by the following constitutional formulæ?

H—Cl, and Cu—O.

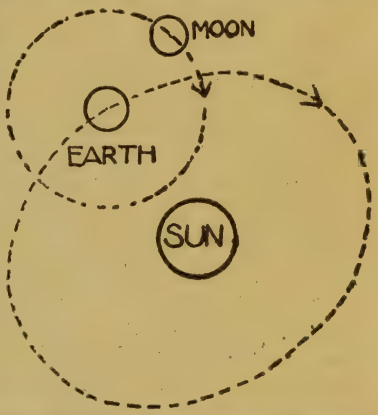


Fig. 8.—The Solar System, showing how the moon goes with the earth and the earth with the sun.

The band or "link" joining the two atoms has here the meaning that the one atom accompanies the other on its journey through space, each atom probably revolving one about the other in the same way that the moon revolves about the earth. Now let us take a somewhat more complicated system, such as that of the moon, earth, and sun. Here the earth revolves round the sun and the moon around the earth in the way depicted in Fig. 8. The earth is, so to speak, connected or linked to the sun, and the moon to the earth. Hence we could pluck away the moon from the whole system without removing the earth; but if we plucked away the earth, the moon would be removed with it. Is not this exactly the same phenomenon that we have met with in the case of the sulphuric acid molecule, where we found that the hydrogen atoms could be removed without removing

oxygen atoms, but that oxygen atoms could not be removed without removing hydrogen atoms with them? A chemist would express these relations which exist between the sun, earth, and moon, by a constitutional formula such as this:

M—E—S

where M, E, and S stand for the moon, earth, and sun. As in the case of the sulphuric acid constitutional formula, the dashes merely show how the particles are linked together; and it is possible that the physical interpretation is the same in both cases.

Just as we removed in succession the moon and the earth from the sun in order to determine the constitution of the system, so chemists remove in succession the different atoms of the molecule in order to elucidate their constitution. The agents which they employ for picking off the atoms are collisions with different sorts of molecules. In other words the chemist "treats" the molecules of the substance with other sorts of molecules and then studies the decomposition products. In this way a marvellous insight is obtained into the actual structure of the molecules.

"In all compounds," says Ira Remsen* "the attempt is made by means of a thorough study of their chemical conduct, to trace out the connections existing between the constituent atoms. When this can be done for all the atoms contained in a molecule, the structure or constitution of the molecule or of the compound is said to be determined. . . . The formulas are but the condensed expressions of the conclusions which are drawn from the reactions." Now reverting to our planetary model we get the following interpretation of our constitutional formula of the sulphuric acid molecule: Firstly, a central sulphur atom (marked 1 in Fig. 9) around which all the other atoms rotate. Next come two oxygen atoms (marked 2 and 3) revolving one about the other, and the combined pair circulating about the central sulphur atom, thus expressing the relation $S<\begin{matrix}O\\|\\O\end{matrix}$ Outside of these come two oxygen atoms (4 and 5) to each

* Introduction to "Organic Chemistry," p. 16.

of which a satellite in the shape of a hydrogen atom is provided. We thus express the relation $\begin{matrix}H—O\\H—O\end{matrix}>S$. We have thus obtained a kinetical interpretation of the entire constitutional formula $\begin{matrix}H—O\\H—O\end{matrix}>S<\begin{matrix}O\\|\\O\end{matrix}$ of sulphuric acid. Probably

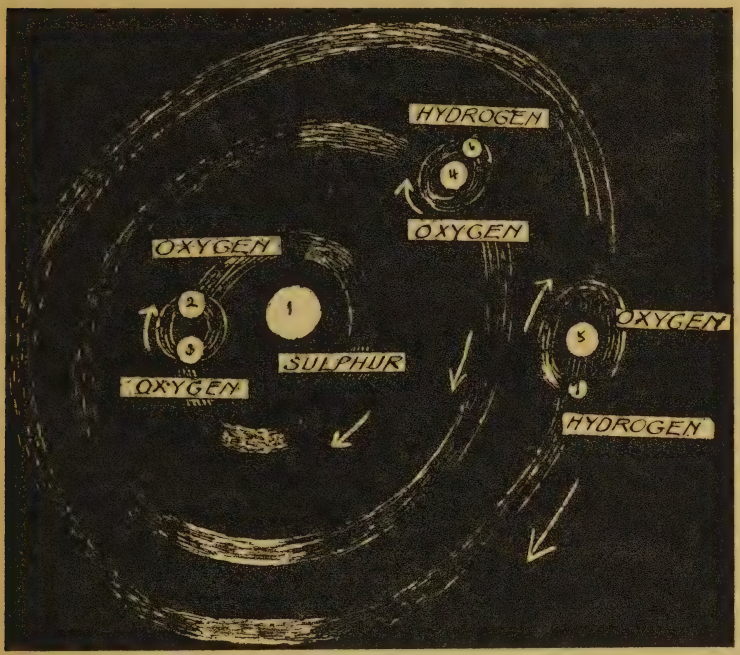


FIG. 9.—Imaginary Representation of a Sulphuric Acid Molecule. This probably consists of a tiny atomic planetary system consisting of a central sulphur atom around which are swiftly revolving a number of other atoms.

the molecule itself is rotating rapidly and the whole may appear like a rapidly rotating wheel.* Other constitutional formula can be similarly interpreted.

* We have indisputable evidence that vastly swift whirling motions actually do go on within the molecules of many substances, the motion being in some substances from right to left and in others

However interesting and instructive such models may be in helping the beginner to realise what the constitutional formulæ of the chemist really mean, the reader must be cautioned against accepting them as absolutely true representations of the molecules. For example, there are some facts which seem to indicate that the sulphur atom has a distinct shape in space and that the atoms rotate round fixed points on its surface rather than round it as a whole, like planets round the sun.

For the present, however, our models may be taken as representing the facts closely enough. In many cases they probably correspond to a real physical representation of the molecules.

Let us now picture to ourselves with the aid of these models the course of the chemical reaction between phos-

from left to right. For example, in magnets we know that the majority of the molecules are arranged so that the orbits of the majority of the electrons, which revolve around the atoms like the planets round the sun, all lie in parallel planes, like the planets in the solar system, with the revolutions in the same sense; and in permanent magnets this parallelism is maintained by the mutual attraction of the orbits of the different molecules. Again, when we send a ray of plane polarised light through a certain modification of tartaric acid (a substance composed of hydrogen, oxygen, and carbon, much used for making effervescing powders) we find that there is a swift rotation going on within the molecules all in the same direction which rotates the plane of polarisation of the ray to the right. If now we send the ray through another modification of tartaric acid, we find that the ray has its plane of polarisation rotated to the same extent, but now to THE LEFT! Chemically the two modifications are similar. The only difference seems to be the physical one that the swift whirl going on within the molecules is in opposite directions in the two modifications. Many other similar cases are known. The investigation of these "optically active" bodies, as chemists call them, has in the hands of Pasteur, van't Hoff, Le Bel, Wislicenus, Pope, Kipping, and others, taught us that certain atoms, like carbon and silicon, have a definite shape, that of a tetrahedron, and that the attached atoms rotate round fixed points at the corners of the tetrahedron. For further information on this wonderfully interesting science of "Stereo-Chemistry," which deals with the shape of the atoms, we may refer the reader to van't Hoff's "The Arrangement of the Atoms in Space" or to Stewart's "Stereo-Chemistry." We have briefly touched on the subject in Chapter II.

FIG. 10.—Reaction between PCl_5 and H_2SO_4. I. The molecules approach each other.

phorus pentachloride and sulphuric acid, a reaction which we have already discussed (p. 70). The change is represented by the following equation :

$$\underset{\text{Sulphuric Acid}}{(HO)_2SO_2} + \underset{\text{Phosphorus Pentachloride}}{PCl_5} = \underset{\text{Phosphorus Oxychloride}}{POCl_3} + \underset{\text{Sulphonyl Dichloride}}{SO_2Cl_2} + \underset{\text{Water}}{H_2O}$$

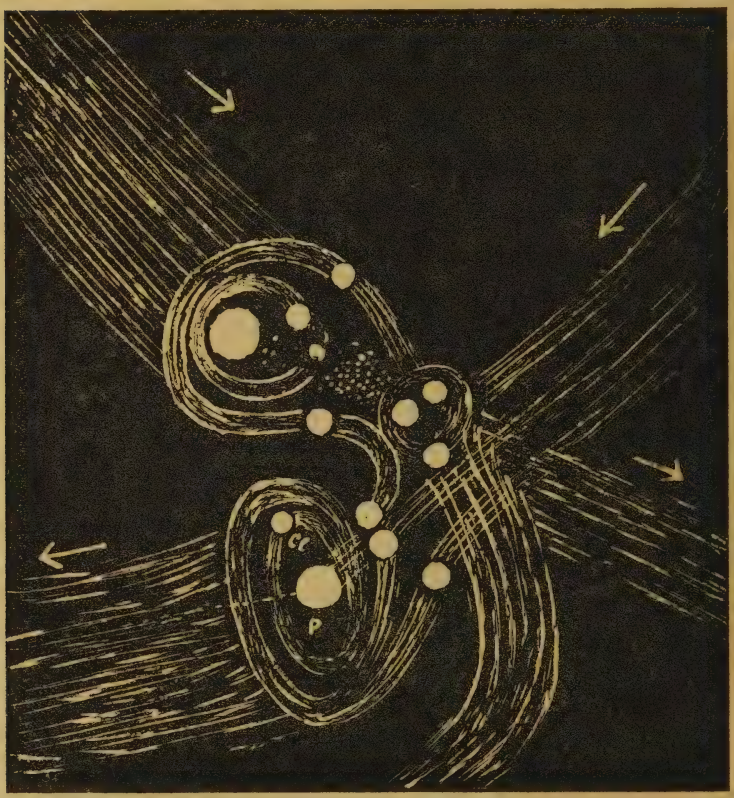


FIG. 11.—Reaction between PCl_5 and H_2SO_4. II. The molecules collide.

We must imagine the molecules of PCl_5 and H_2SO_4 rushing together in opposite directions, with all their atoms whirling round them, as in Fig. 10. They meet (Fig. 11). The individual atoms become entangled each in the other's

sphere of influence. Two chlorine atoms rush in towards the sulphur atom and continue revolving about it. All is over in an instant, and there fly away (Fig. 12) the three molecular systems $POCl_3$, H_2O, and Cl_2SO_2, produced by the shattering of the original molecular systems.

How serious a matter such a collision as that here pictured must be for the constituent atoms of the molecules, will best

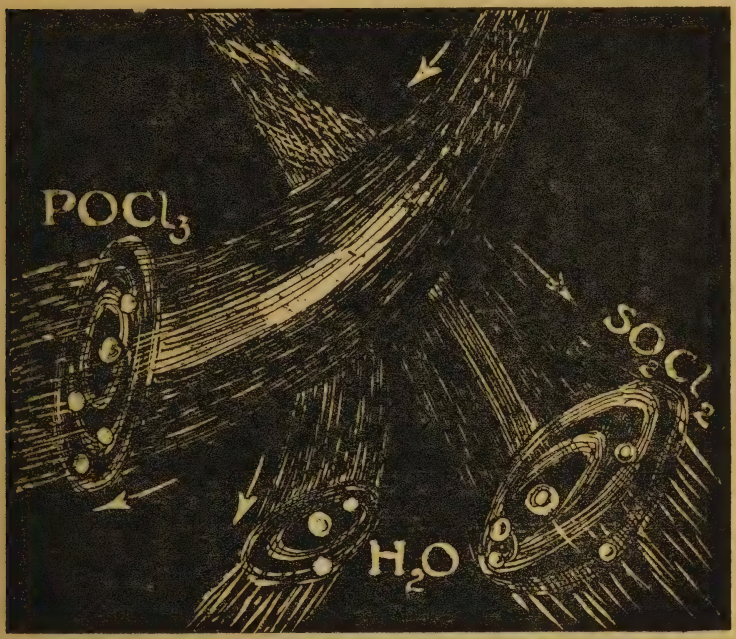


FIG. 12.—Reaction between PCl_5 and H_2SO_4. III. Formation of the molecules $POCl_3$, H_2O, and SO_2Cl_2 as the result of collision.

be realised by imagining the encounter of our solar system with one of the dark suns of space, an event which, perhaps, would afford the nearest analogy that we are acquainted with to such a molecular collision. If the sun and star actually collided both bodies would be reduced to a mass of flaming gas within an hour, and the sudden generation of heat would be so great that the whole surface of the earth

would be burnt to a cinder within a few seconds. Perhaps, indeed, the earth would be actually gasified and, along with the other planets of the solar system, overwhelmed

"In unremorseful folds of rolling fire."

More probably, however, such a dark sun would sweep through the solar system without actually colliding with any planet, and after grazing the sun like a comet, would retreat along a curve like an ellipse, bearing with it into space some of the planets of the solar system, and leaving behind it some of its own. Even in this case the event would be an unpleasant one. For if the invading sun approached the earth, its attraction would uplift great areas of the earth's crust, tearing them away and releasing strains and forces underneath. Such terrible volcanic eruptions, such floods of lava, such storms and earthquakes would result, that probably every living thing upon the earth would be killed in the course of a few hours, except perhaps a few of the lowest bacteria. If it approached the sun, the same pulling action of gravity would cause great arms of flame, millions of miles long, to leap out from the sun. And finally, if such a body merely approached our system, it might produce such an alteration in the orbits of the planets as to make them unstable, and give rise to the possibility that the planets themselves would fall into the sun.

The facts that we have discussed in this chapter led the great Russian chemist, Mendeléef, to draw some interesting comparisons between the atomic and stellar universes. He compares molecules of hydrogen, oxygen, and water to the systems of double or triple stars found in space. In a work published shortly before his death he compares in beautiful language the atoms to the heavenly bodies, such as the sun, planets, satellites and comets, which are eternally wheeling in space, and he then likens the building up of molecules from atoms, and of substances from molecules, to the building up of systems, such as the solar system, or of those wonderful twin stars—colossal suns circulating about each other in highly elliptical orbits—which modern astronomy has revealed to us, and even of whole constellations,

which likewise are built up of individual bodies. So that according to Mendeléef the whole visible stellar universe, with its millions of rushing suns, is merely on the large scale an image of what the atomic universe is on the small scale. He believes this to be no mere fancy, but " a reality which directs the course of all chemical research, analysis and synthesis."*

The modern electronic theory of matter, as developed recently in the hands of the Cambridge School of physicists, with J. J. Thomson at their head, would make the resemblance between the solar system and an atom even more startling, as has been shown by Fournier d'Albe in his book on " The Electron Theory," where the analogy is worked out in detail. He shows that if the solar system is but an atom on the large scale, the sun must be regarded as a positive nucleus and the planets as electrons. He then shows that the sun actually is charged positively and the planets negatively, although the electrical forces which act between them is not sufficient to effect or control their motion to a perceptible extent, so that here the analogy breaks down. He points out that the mass of Jupiter is the one-thousandth part of that of the sun, and consequently approaches the mass of an electron in comparison with that of a hydrogen atom. The mass of the earth is only the three-hundred thousandth part of that of the sun and so bears the same ratio to this body as an electron bears to a heavy atom, like that of mercury or lead. Like the atoms of matter, the solar system as a whole is electrically neutral, the negative charges on the planets counterbalancing the positive electrical charge on the sun. He shows, moreover, that if a neutral external solar system were to approach our solar system and were to capture a planet like Neptune or Uranus, we should have an illustration of what is so common an event in chemistry of two atoms combining, and then separating with opposite electrical charges—our solar system being positively charged, because it has lost a negative electron (Neptune), while the

* " A Chemical Conception of the Ether," p. 6 (1904). The same idea occurs in one or two places in his wonderful book, " The Principles of Chemistry."

other solar system would be negative because it has gained a negative electron.

Extending these observations to the whole visible universe he points out that the individual stars are separated so widely that they do not interfere with each other's motions or planets to an appreciable extent, and that it therefore approaches in constitution to a gas rather than to a liquid or solid. In fact, if the Milky Way, with its millions of suns, were reduced in magnitude in the proportion that an electron bears to an atom, it would appear of about the same size and complexity as a human blood corpuscle with its swarming millions of atoms. In order to achieve such a reduction of the visible universe we must diminish its magnitude in the ratio of 10^{22} to 1, and if we do this we find that the solar system, with a radius of 10^{14} cms, becomes then of atomic dimensions, with a radius of 10^{-8} cms.* The distance between our sun and the nearest fixed star is about 10^{18} cms. and this when reduced in the same ratio becomes 10^{-4} cms.,* which is approximately the mean free path of a molecule in a somewhat attenuated gas.

On the other hand if we magnify the tiny world of the atom by the factor 10^{22} leaving all the velocities unchanged, we should then cause an oxygen atom, or any similar atom, to become of the same size as the solar system, and its two negative electrons would closely resemble Neptune and Uranus both as regards size, distance from the centre, and period of revolution.

The interior planets, such as the earth, would then represent magnified electrons, which in the atoms cause the phenomenon of magnetism and radiation. Indeed, as Fournier d'Albe points out, the tiny electrons may have a constitution resembling in every particular that of the earth, and yet we should not only never become aware of this on account of the almost inconceivable minuteness of these bodies, but such a structure would not affect their astronomical or electrical properties in the slightest. The electron may be a veritable microcosm, "a world on which life may flourish not very different from life upon this earth,"

* 10^{-8} means, $\frac{1}{10^8}$, *i.e.*, $\frac{1}{100000000}$; similarly 10^{-4} means $\frac{1}{10^4}$, or $\frac{1}{10000}$.

without any one being the wiser. Such thoughts make us realise that the universe may have within it depths of complexities altogether unsuspected by ourselves. Indeed the authority referred to points out that if our world and all that is therein were suddenly reduced by some magical power to atomic dimensions, our instruments would never indicate, and we should never know, that such a change had taken place, because space and time were simultaneously diminished in the same proportion. Conversely if an intelligent inhabitant of our electronic microcosm were suddenly transferred to our world, and managed to retain his mental characteristics unchanged, our life here, busy as it seems to us, would represent to him a changeless eternity, since in a single second of our time the electronic world has time to revolve billions of times round its central sun. His atomic years are almost infinitely shorter than ours and his sense of time almost infinitely finer. Time and space are, after all, merely relative conceptions.*

Such thoughts of a minute microcosm insensibly remind us of Morris's words :—

> "Where did the idea dwell
> Which held within the atom and the cell
> The whole vast hidden Universe, sheltered well,
> Till the hour came to unfold it, and the need ?"

The reader, however, must be warned not to press such analogies too closely. Such wide differences exist between gravitational and chemical forces that it is doubtful whether a direct comparison can be made without the grave risk of misleading the student. So far as we know, the chemical phenomena of valency, stereo-chemistry, and crystallography are not paralleled by the stars. The atomic and the Newtonian universes may be and probably are built up on entirely different models.

* For a further account of these interesting ideas of Fournier d'Albe the reader is referred to his works.

CHAPTER V

WATER

THE antiquity of the ocean is immense. Byron's words :

> " Time writes no wrinkle on thy azure brow,
> Such as creation's dawn beheld, thou rollest now ! "

are probably more scientifically exact than even the poet imagined ; for as far back into the vista of bygone ages as the science of Geology goes, we always find that the great ocean was composed of water as it is now, water swept by storms and tides, water swarming with a myriad forms of life. It is the land not the ocean that has changed. The waves of the early oceans broke against shores which have long since vanished ; while fertile islands and great continents which then existed, supporting innumerable forms of life, are now buried deep under the sea, a fact which was expressed by Tennyson in the well-known lines :

> " There rolls the deep where grew the tree,
> O Earth, what changes hast thou seen !
> There where the long street roars hath been
> The stillness of the central sea."

During the ages which have elapsed since the first oceans were deposited the whole order of creation has had time to evolve, animalacule ascending to man, diatom to mighty trees. Nevertheless, throughout all this vast time the sea has remained unchanged, " the same yesterday, to-day and forever." The very spray which dashes in our faces as we walk along the sea-coast has bathed animals and plants which lived millions of years ago, and probably it will bathe plants and animals living millions of years hence ! Compared with the ocean man is a thing of yesterday. All this has been

expressed in grand and beautiful language by the American poet Braithwaite in his Ode to the Sea.*

"The earth is our mother, but thou—thou art father of us and of time;
For all things now were not when thou wast strong in thy prime.
There was silence first, and then darkness, and under the garment of these
Was the body of thee in thy might, with its infinite mysteries.

* * * * * *

For earth he made out of dust, for change and defeat in the blast;
But thee he made eternal, thro' aeons and aeons to last,
Unmarked by sun or wind, and supreme where thy waves are tossed;
Not an inch of thy beauty to perish, not an ounce of thy might to be lost."

It is possible to arrive at an estimate of the age of the ocean. Prof. Joly has shown that if we calculate the amount of salt yearly added to the sea by means of rivers, and compare this with the amount of salt already in it, one must conclude that at least 100 million years have elapsed since the first waters of the ocean were deposited!

The amount of water upon the globe is truly stupendous. The waters of the ocean alone would, if gathered together in one mass, form a globe about 850 miles in diameter!† Over three-quarters of the surface of the globe is covered with water. The average depth of the depression occupied by the ocean is 14,640 feet, or nearly three miles. The greatest known depth of sea is 31,700 feet, or 6 miles. In these depths an utter silence and darkness has reigned for ages; no human eye has ever beheld these abysmal valleys, no ripple has ever broken upon their shores, no play of light from above has ever illuminated their mighty slopes. Their waters are cold as melting ice itself. The pressure of the water in these silent and dark valleys is enormous, being about six tons to the square inch. The stoutest steam boiler ever made by man would yield and tear like tissue paper under such a pressure; and yet, in spite of this, a world of

* *Century Magazine* (1907), Vol. 74, p. 710, reproduced by kind permission of Macmillan & Co.

† Bonney, "The Story of our Planet," p. 14.

animals, many of them quite unknown to man, live in these dreadful deeps. Kipling in his "Sea Cables" has drawn a vivid picture of the bed of the deep ocean :

"The wrecks dissolve above us ; their dust drops down from afar
Down to the dark, to the utter dark, where the blind white sea-snakes are.
There is no sound, no echo of sound, in the deserts of the deep,
Of the great grey level plains of ooze, where the shell-burred cables sleep."*

For the origin of the mighty masses of water which constitute our oceans we must go back to a period in the history of our globe long antecedent to geological history, when our world still formed part of the vast gaseous nebula from which the solar system evolved. This nebula contained the elementary gases hydrogen and oxygen. As it cooled these gases gradually combined to form (as we will presently show) water vapour. Presently when the world condensed to a white hot fluid mass, it was encircled with a vast girdle of invisible water vapour topped with enormous clouds of steam. The whole of the huge volume of water which now stretches from continent to continent and girdles the globe was then supported in the state of high pressure steam by the molten surface of the earth. The pressure exerted by this and other gases which have long since disappeared into the earth's crust, must have been enormous. It may have been as much as ten tons on the square inch ! The temperatures and pressures within the boilers of our most powerful steam engines are quite insignificant when compared to those which prevailed within such a giant boiler as our earth's surface formed at that remote time. These conditions did not last very long. The temperature of the world's surface rapidly fell from a white heat to a low red heat. When it reached a temperature of about 370° C. water for the first time began to be deposited upon the surface of the globe, this being the highest temperature at which steam can condense to water at a high pressure.

This was a marvellous period in the history of our planet; for almost the whole of the vast mass of liquid now found

* From "The Seven Seas," by kind permission of Mr. Kipling and his publishers, Methuen & Co.

in the oceans condensed from steam to water within a period which Lord Kelvin reckons could not have exceeded one hundred years, and which Arrhenius thinks could not have been longer than a few thousand years! First there came on a Niagara-like torrent of almost red-hot rain (at a temperature of 370° C.). The volume of the water then descending from the sky can now scarcely be realised; perhaps a feeble representation of these early torrents may be seen in the water-spouts which sometimes devastate tropical seas; for huge quantities of water must have been ever condensing in the upper cool regions of the air and continually pouring upon the red-hot surface of the earth below, only to be hurled aloft again, mingled with molten débris, in a series of vast explosions. How strange that early world must have looked. Imagine its surface a vast plain of liquid fire; above, black driving vapour and great clouds of steam glaring red from the glow of the bubbling molten rocks beneath. Below, hurricanes and cyclones inconceivably more terrible than any that now occur upon the earth, continually sweeping vast masses of rolling vapours and liquids in huge waves across the blazing seas!

This went on during the whole time (and probably for some time previously too) that elapsed between the formation of the first solid crust of the earth (at about 1000° C.) and the cooling of this crust, a few thousand years later, to 100° C. If astronomers are to be believed such scenes are even now being enacted on the mighty planets Jupiter, Saturn, Neptune, and Uranus, although it is hard to realise this when we see them shining with such apparent quiet in the sky at night.

The temperature of the oceans then rapidly sank from 100° C. until it reached 55° C., a temperature at which certain seaweeds (Algæ) now exist in the hot springs of New Zealand and America. Since then the temperature of the ocean has declined gradually until it has reached its present value. According to Arrhenius the earth must have been in a fit condition for maintaining life quite a short time after the deposition of the oceans.*

* Arrhenius, "Das Werden der Welten," p. 36.

The reader, however, must not imagine that the earth has even now completely cooled. Its interior is still white hot, perhaps so hot as to be gaseous. Its surface is still at a temperature nearly 300° C. above that of external space. Indeed to beings accustomed to the coldness and darkness of external space (for away from the immediate vicinity of our sun all is as dark as the darkest night and almost as cold as the absolute zero of temperature itself) the world would be almost as hot as molten lead is to us! It must not be forgotten that the earth's surface is still so hot that over three-quarters of it is in a fused or molten condition! For water is nothing but a molten rock. Ice, in fact, has as much right to be regarded as a rock as has quartz or granite. Indeed, in early times vast seas of molten granite and quartz existed just as there now exist seas of molten or fused ice.

The process of cooling has by no means come to an end. The earth is still cooling and there will surely come a time when its average temperature will sink from its present value (17° C.) to nearly—273° C.—the absolute zero of temperature itself.*

Even at the present time the temperature of the world is only slightly above the temperature at which all its water will pass into the solid state. Indeed the process of solidification has already commenced. Large regions exist where all the water has passed permanently into the solid condition; and these regions will extend with time until all the seas and the mighty oceans themselves will freeze and be converted from top to bottom into vast masses of ice. Water will appear to the inhabitants of future days (if any exist) as

* The present temperature of the earth's surface depends essentially upon the radiation from the sun. The amount of heat filtering up through the badly-conducting crust of the earth is not sufficient to warm the surface much. The cooling will follow on account of the diminution of heat and light from the sun. For there exists little doubt that the sun will in the course of time grow dim and finally go out, leaving the world dark and desolate. Future research, however, must decide to what extent these conclusions must be modified owing to the presence of heat-evolving radium disseminated throughout the earth and sun.

solid deposits of mineral matter presenting to them much the same appearance as the white masses of marble rocks in certain parts of the world present to us !

Water is not confined to our earth alone. It is said to have been detected on our sister planet Venus, a body about the same size as the earth. She is surrounded by a deep dense atmosphere in which float vast masses of white clouds. These, no doubt, are similarly constituted to the clouds which occur on the earth and consist of minute drops of water. Some observations by Cruithuisen and Trouvelet seem to indicate the presence of snowy polar regions. Very probably under the layer of clouds which cover this planet

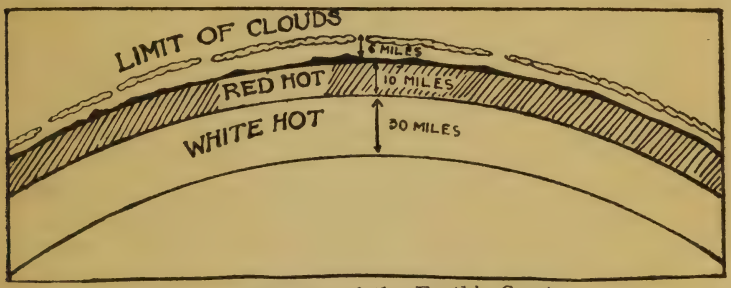


FIG. 13.—Section of the Earth's Crust.

there exist large oceans and rivers similar to our own. Water certainly exists on Mars. It has been detected there by means of the spectroscope. We can actually see the snow collecting around her poles in the winter time which in the spring rapidly melts and turns into dark masses of water. Sometimes, indeed, during the summer months, the masses of snow melt away completely, a thing which never happens in our polar regions. The surfaces of the larger planets, Jupiter, Saturn, and Neptune are largely composed of vast steam clouds floating above a hot mass of molten rock. Water is thus generally disseminated throughout the solar system. It is, in fact, a universal body. Let us now leave the solar system altogether and cast our eyes upon :

> " The fires which arch this dusky dot—
> Yon myriad worlded way—
> The vast sun-clusters' gathered blaze,
> World-isles in lonely skies."

We see that there exist scattered throughout the limitless universe innumerable suns, around each of which whirl dark little worlds like our own. The thought is irresistible that many of these, too, must contain great seas, rivers, and broad expanses of water glittering in the light of suns that we have never seen. If this be so, and there seems no reason why we should doubt it, the mass of water which occurs on the earth, vast as it appears to us, vanishes altogether in comparison with the inconceivably greater quantity disseminated through the depths of space.

We have every reason to believe that there is now considerably less water upon the surface of the globe than there was formerly. The seas have probably been steadily shrinking for ages, and may ultimately disappear altogether from the earth, as they have already done in the case of the moon. The reason of this is that the minerals of the earth's crust are continually absorbing water from the ocean.

"Water," says Milton, the author of "The Stream of Life," "penetrates into everything. . . . Nearly all the earths, flint, lime, alum, magnesia, and clay are pervaded by its influence. All soils, even the hardest, contain water in abundance, few having less than one-eleventh, some being nearly half water. It penetrates into every rock, till sandstone becomes so full of it that one or two million gallons of water can be pumped daily from a single well, while chalk is still fuller of water. . . . Granite is supposed to contain two gallons of water in each cubic yard."

The extent to which this absorption of the waters of the sea by minerals has gone on is almost incredible.

It has been estimated that more than a third of the ocean has disappeared already owing to this cause. The bottoms of the seas and lakes are leaky and allow the water to filter down slowly into the earth's crust. In many cases it reaches the white-hot regions of the interior, and is here converted into steam under an enormous pressure, and this plays an important part in causing volcanic eruptions. Most volcanoes are situated near the sea or near large lakes.

Mr. Grew, in his charming book "The Romance of Modern Geology," thus illustrates how the sea sinks into the earth

under the enormous pressures which exist in its deepest parts :—

" Some years ago, when certain officers of the United States Navy were making ocean surveys, it was found that if hollow balls of thick glass were sunk to great depths in the ocean, they came up more or less completely filled with water in proportion as the depth increased, though no breakage or cracking of the glass had occurred, and no holes in it could be discovered even by the best microscopes. In other words, it became evident that water had been slowly but bodily forced through the thick walls of the glass (under a pressure of less than 15,000 lb. to the square inch) in less than an hour's time. Evidently, then, even such a substance as glass will be penetrated by water if the pressure is great enough. . . . In deep places (of the ocean) the pressure of the sea water (on the ocean bottoms) is very great, sufficient to force water through glass. Obviously most of these bottoms will leak, and leak at a rapid rate under the enormous pressure operating in the greatest depths of the sea. . . . To see how effective the pressure arising from the depths of the ocean may be in driving water into the crust of the earth, we may observe that the tendency to penetrate it is everywhere proportional to the depth of the sea. . . . Now some of the ocean depths exceed five miles, the greatest, near Guam, being 5,289 fathoms, almost exactly six miles. Is it any wonder that the deeps east of Japan, near the Aleutian Island, west of South America, near Guam, between Samoa and New Zealand, give rise to enormous leakage of the sea bottom, and consequently many world-shaking earthquakes ? . . . What may be expected of a constant water pressure which will throw a jet five miles high ? Such is the pressure all over the bed of the Tuscarora Deep, and it continues from year to year, century to century. It is this pressure which forces the water so rapidly into the earth, and gives rise to all the great earthquakes and sea-waves with which Japan is afflicted. No stone on earth, however thick its layers, could withstand such a pressure ; nay, under it the water would go through the hardest metals, and sink down deeper and deeper into the bowels of the earth. Thus subterranean steam would arise beneath the crust and accumulate till relief was afforded by a shaking of the earth."—(" Romance of Modern Geology," by E. S. Grew, 1909, pp. 182, 189, 190. Quoted by the courtesy of Seeley & Co.).

The white-hot interior of the earth, which begins twenty to forty miles down, presents an insuperable bar to the further diffusion of water. When the liquid reaches this limit it is expelled again as steam or gas.

If the whole interior of the earth were to become cool suddenly, its waters would begin to sink rapidly into it,

just as they would into a mass of blotting paper or into a loaf of bread, and in a very few centuries its surface would be as devoid of water as is the Sahara desert. The same fate would overtake the air, and the whole earth would thus become a huge, desolate waste of airless and waterless desert, covered with mountains and plains silent and changeless like those of the moon :

> " Where never creeps a cloud or moves a wind,
> Nor ever falls the least white star of snow,
> Nor ever lowest roll of thunder moans,
> Nor sound of human sorrow mounts to mar
> Their sacred, everlasting calm."*

It is thus the earth's internal heat which, so to speak, keeps it alive on its outer surface.

In earlier ages this zone of white-hot rock was much nearer the surface than it is now, and consequently the waters which have retreated within the earth's crust then filled the early seas to overflowing. Indeed, probably no land whatever appeared above the surface of the ocean, and the whole earth was one great waste of moving waters. Even so recently as the carboniferous era great plains existed periodically inundated with water to the depth of only a few inches or feet. Sometimes these districts were as broad as modern France. Naturally they turned into huge tangled swamps choked up with a luxuriant and gigantic vegetation whose decayed remains constitute our coal. It is only now, after ages of steady shrinkage, that the seas keep strictly to the limits assigned to them.

Water enters very intimately into the constitution of living matter. " Of the human frame," says a writer of the last century,† " water forms so large a part that the most thoroughly smoke-dried old crone who ever ran the risk of being burnt for a witch would shrink visibly if all the water were drawn off from her withered frame. A gentleman of comfortable dimensions if distilled quite dry would be transformed into a respectably dressed mummy, and the famous Daniel Lambert (who

* Tennyson, " Lucretius." † " Stream of Life," p. 566.

weighed 53 stone at the time of his death, was nine feet four round the body, three feet round the leg, and could carry five hundredweight with ease) under this draining process would have dwindled to the weight of a small young gentleman in knickerbockers. . . . Every day of his life man throws out by his skin and lungs quite two pounds of water. Without water he could not bend a muscle or feel by a nerve; the atoms of every bone are dissolved or diffused in water before being built up. All tissues owe their flexibility to water, of which they contain at least four-fifths, mechanically or vitally, not chemically, combined with the animal matter, which deprived of its water becomes wholly insusceptible of vitality."

Plants, too, contain equally large amounts of water. Water plants often contain 95 to 98 per cent. of it, and land plants 50 to 70 per cent.

We may well inquire at this stage what is there peculiar in water which thus causes it to enter so largely into the constitution of living matter? The chemist will answer: Nothing! Neither chemically nor physically is there anything which inherently distinguishes water from hundreds of other liquids. Every property exhibited by water is shared, to a greater or less extent, by many other liquids.

The reason why water enters so largely into the constitution of living matter is probably due to the accidental circumstance that it is extremely abundant and at one time covered the whole earth.

It is always very futile to speculate upon subjects, such as the nature of life, about which nothing is definitely known; yet we cannot help suspecting that the enormous amount of water in living matter is due to the fact that our present forms of life all originated in the fluid sea and thence spread to land. In the earliest times, when the waters of the seas were still warmed by the internal heat of the earth, they were probably filled with enormous quantities of gelatinous and formless living matter, which floated in island-large masses, and covered the steaming oceans as with a viscid mass. All the different animals of to-day differentiated and developed out of such simple vital forms. "It is at least probable,"

says Scott Elliott in his charming book,* " that the first real plant on this world was a sea-weed or algæ. In Germany and Austria there are certain springs in which water coming up from immense depths is at an exceedingly high temperature. These hot springs are used as natural hot baths, and have many interesting peculiarities. Amongst others is the fact that certain seaweeds or algæ are found luxuriating in the hot water. Some of these can even live in springs with a temperature of 176° F. (80° C.) ! Such algæ may have remained living in exceedingly hot water ever since that long distant time, the very first of all geological periods, when there was no distinct separation between land and water, and when the waters which were below the firmament had not been separated from those above it."

If life really did first originate in water it is very natural that living matter should have retained within it large quantities of the medium which first surrounded it on all sides. Indeed it was absolutely necessary that water should have been able to penetrate it freely through and through to every part, otherwise the organism could not have withdrawn from the sea its nourishment in the form of dissolved salts. We must remember that such early forms of life had no special organs for assimilating food. The food simply had to diffuse slowly from the sea into every part of the organism. Even after ages of evolution probably all our food enters our bodies thus dissolved in watery fluids. This fact explains, too, why the early forms of life were gelatinous and not crystalline. For salts will diffuse as easily through an aqueous jelly saturated with water as through pure water itself.

If the early seas had consisted of petroleum or alcohol, no doubt forms of life would have come into existence which contained as much of these liquids as they now contain water. At least there is nothing in the science of chemistry which opposes this supposition.

Such considerations should teach us to be very careful as to how we dogmatise on the impossibility of life occurring

* " Romance of Plant Life," p. 200 (1907). Quoted by kind permission of Seeley & Co.

under conditions absolutely different from those now prevailing upon the earth. Until we know what life is it is unscientific to decide beforehand what is possible and what is impossible. Life probably adapts itself to the planet in which it occurs, much as water adapts itself to the vessel which holds it. It develops in those forms of inorganic matter which it finds in a suitable condition ready to hand. On our planet it has developed in material consisting mainly of the elements carbon, hydrogen, oxygen and nitrogen. On other planets it may have developed in matter consisting of entirely different elements. One must not even exclude the possibility of life occurring in red or white-hot matter—though of course such living matter could not possibly be formed of the same elements which build up the vital matter which occurs upon the earth.* If this be so the enormous bulk of material in a white-hot or red-hot condition now scattered throughout the universe may not be so absolutely useless for vital purposes as it at present seems to be.

I suppose that no one now seriously maintains that a vast mass of matter like the sun, a mass 300,000 times greater than that of the earth, exists solely for the purpose of allowing that noble animal Man to live with some degree of comfort! Perhaps, after all, the main object of the universe is not to convert as large an amount of its material as possible into an animate form. There may be more important objects to be achieved than that, objects of which no man has ever had or can have the faintest inkling. As was remarked of old, there are more things in heaven and earth than are dreamt of in man's philosophy.

Indeed, it is quite probable that all life is single in its essence, that men and all living creatures are but sharers in a vastly more extended scheme of cosmic action than we are aware of; that we are, in fact, but portions of an infinite whole, of a mighty universal system comprising untold millions of worlds each crowded with living forms, the whole swiftly evolving towards ends quite as unknown to us as to the lowest forms of life. Modern science has

* See a series of papers by the author in *Knowledge* for 1905, and in *Science Gossip* (1900), in which these questions are discussed.

opened out a vista of possibilities which were unknown to Tennyson when he penned the words:

"Raving politics, never at rest—as this poor earth's pale history runs—
What is it all but a trouble of ants in the gleam of a million million of suns?"

Few facts are more wonderful than the continual circulation of water over the surface of our planet. From the time the first drop of water fell upon our earth until now it has never ceased to circulate, changing the face of continents, wearing down mountains into plains, and plains into valleys. This circulation is maintained by the heat of the sun. The sun evaporates the water and causes it to rise in the form of invisible vapour, which then condenses to clouds and falls again upon the earth as rain; thence by means of a thousand streams and rivulets it ultimately finds its way to the great ocean again. Indeed, as was long ago remarked, "The rain which we see descending was thawed for us out of icebergs which have watched the polar star for ages: and lotus lilies sucked up from the Nile and exhaled as vapours the snows that are lying on the tops of our hills." An active agent in diffusing vapour and in maintaining the circulation of water is vegetation of all kinds and especially trees—a fact which explains their beneficial influence upon climate. The present practically desert condition of countries like Babylonia and Northern Africa, countries once famed in ancient times for the fertility of their soil, is believed to be due, in part, at least, to the deprivation of these lands of their trees.

"All plants," says Scott Elliott, "contain a large percentage of water. This may be as much as 95 to 99 per cent. in water plants, and 50 to 70 per cent. in ordinary land plants; it is contained in every sort of vegetable substance. But there is also a stream of water or sap rising up the stem and passing into the leaves. On these leaves there are hundreds of minute openings called stomata, by which water escapes as water-vapour into the atmosphere. A single oak leaf may contain as many as 2,000,000 of these stomata. It is this current of sap which keeps the leaf fresh and vigorous; it is also by this current that every living

cell is supplied with water and kept in a strong healthy condition. The amount of water used in this way is very great; in four months an acre of cabbages will transpire or give out through its leaves 3,500,000 pints of water, and an acre of hops from 5½ to 7,000,000. A single oak tree, supposed to have 700,000 leaves, must apparently have given off into the atmosphere during five months 230,000 lbs. of water.*

Now, trees live to an immense age. Many oaks live to well over a thousand years. Some of the "mammoth" or "big" trees of California are certainly over 3,000 years old. The age of the Dragon Tree of Oratava in the Canary Islands has been estimated by some authorities at 8,000 years, while others have estimated its age at 10,000 years. This tree, therefore, was hoary with age at the time that Homer was composing his songs or when Abraham was watering his flocks and herds!

Now a little calculation will show that a single oak tree 1000 years old will in the course of its existence give off something like 250,000 tons of water! Some of the older trees may well have given off a million tons of water! When one reflects upon the myriads upon myriads of trees, plants, flowers, and grasses, which have been continually flourishing year in and year out for countless ages, and giving off water during the whole of this time, one can easily realise what a stupendous amount of water must have been thrown into the air by plants. Whole oceans must have been used up again and again by the vegetable world.

The great changes which take place upon our earth are effected, not by the great rivers and lakes, though these take their share in the process, but principally by the unseen waters. The Ganges, rushing in the flood season at the rate of nine miles an hour and bearing with it in its waters to the sea seven thousand million tons of earth, or the Mississippi, yearly rending away whole islands by the force and volume of its current, effect far less change in the course of a year than the innumerable tiny streams or rivulets which flow down countless valleys to the sea. The principal rivers do

* "Romance of Plant Life," pp. 23, 24.

not carry off more than one-sixth of the total rainfall even in tropical climates.

Water has truly been compared to the blood and chyle of the body. Without it there could be no life in the sense that we understand the term. "Death would reign everywhere, silence and stillness would take the place of that universal movement which now characterises our earth." The hills would cease to be washed away, the valleys and plains to be disintegrated. Every stone which now lies loose on its surface would lie there through untold ages, unchanged and unmoved.

The influence that the invisible water vapour in the air exerts in causing us to have an equitable and mild climate cannot at first be realised easily. This vapour absorbs the dark rays from the sun, and prevents the earth from radiating away its heat into space too rapidly. It thus acts as a blanket to the earth, preventing us from being scorched by the direct rays of the sun in the day-time, and from being chilled by more than arctic frosts in the night-time. On the moon, where the sheltering action of atmosphere and aqueous vapour is absent, the temperature of its surface rises to about 180° C. in the day-time and sinks to about—250° C. at night! Mutton could easily be roasted in direct sunlight there, while air could not only be liquefied, but actually frozen hard, by the intense cold prevailing at night!

The weather, which now provides us with an unending topic for conversation and complaint, would cease to interest us on a waterless globe. There would be no rain, no snow, no hail, no frost. Nothing but blinding sunshine or darkest night!

One of the first questions which arises in the mind of a student when approaching for the first time the chemical study of water is this: Of what is this abundant and useful liquid composed? The answer is: Of invisible gases! Yes, strange as it may appear, especially when we view breakers rolling inwards upon the sea-shore, the whole mass of water in the sea is composed of the invisible gases hydrogen and oxygen, elements of which we will presently treat, compressed together by the mighty forces of chemical affinity to nearly the eighteen-hundredth part of the volume

they occupy at ordinary temperatures and pressures. To do this by pressure alone would require the application of nearly four million pounds per square foot ! If, by means of some cosmic influence acting through space, the forces which hold the oxygen and hydrogen gases imprisoned within the water molecules were suddenly slackened, the oceans would instantly be resolved into a vast mass of highly compressed gas, which, with a roar like a vast thunder peal, would ex-

FIG. 14.—If water suddenly became incompressible the sea would rise 116 feet above its present level, and would rush over the land burying cities beneath its waves.

pand, rushing upwards with an irresistible force until it had occupied a volume considerably greater than twice the volume of the whole earth, and had formed about it an atmosphere extending upwards for over a thousand miles ! Such an atmosphere would produce a pressure upon the surface of the globe of over three tons per square inch, a pressure sufficient to crush a man as he is now constituted into a formless pulp.

Water, in fact, is composed of hydrogen and oxygen united together in the proportion of nearly two volumes of the former gas to one of the latter. A cubic inch of water contains 1,234 cubic inches of hydrogen united to 617 cubic inches of oxygen, both gases being supposed to be measured at 0° C. and 760 millimetres pressure.

Water is at ordinary temperatures a liquid possessing a very faint bluish-green colour, well seen in the colour of the ocean and in certain lakes. Our earth, seen from outside, must appear as a greenish planet capped with snowy poles.

Water is an almost incompressible fluid, one million volumes diminishing by only fifty when the atmospheric pressure is doubled. Slight as this compressibility may seem to us, yet, as Prof. Tait has shown, it produces most important results. At the bottom of the dark abysses of the ocean, nearly six miles deep, the pressure must amount to 1000 atmospheres. The result of this compression is to make the surface-level of the general mass of the oceans some 116 feet lower than it would be if the water were perfectly incompressible. If water suddenly ceased to be compressible the great oceans would instantly rise 116 feet in height and pour in a mighty flood over low-lying lands. Over 2,000,000 square miles of land, something like four per cent. of the whole land area of the globe, would be submerged by the torrent,* the hills appearing above the waters as small islands.

Fresh water freezes at 0° C., sea-water at about—2.8° C. The fresh water in our ponds and lakes always freezes first upon the surface. If we dip a thermometer into the water below the ice we shall find always that it is warmer than the ice above, being about 4° C. The reason of this is as follows: The ordinary rule for the contraction of water is that it shrinks with cold and expands with heat. As water shrinks it becomes denser and therefore heavier, bulk for bulk. Consequently, when a low atmospheric temperature acts upon the surface of a pond or lake, the water as it is cooled at the surface becomes heavier and goes down. The surface

* "Challenger" Report, "Physics and Chemistry," II. part 1., p. 76.

layers of cold water keep on sinking, while fresh and warm water, which is lighter, keeps on floating to the surface until the whole mass of water is cooled down to about 4° C. At this temperature fresh water attains its maximum density; in other words a given bulk of water weighs more at 4° C. than at any other temperature, and so will sink to the bottom of the pond. On cooling below 4° C. the fresh water begins to expand again. The greater cold makes it lighter instead

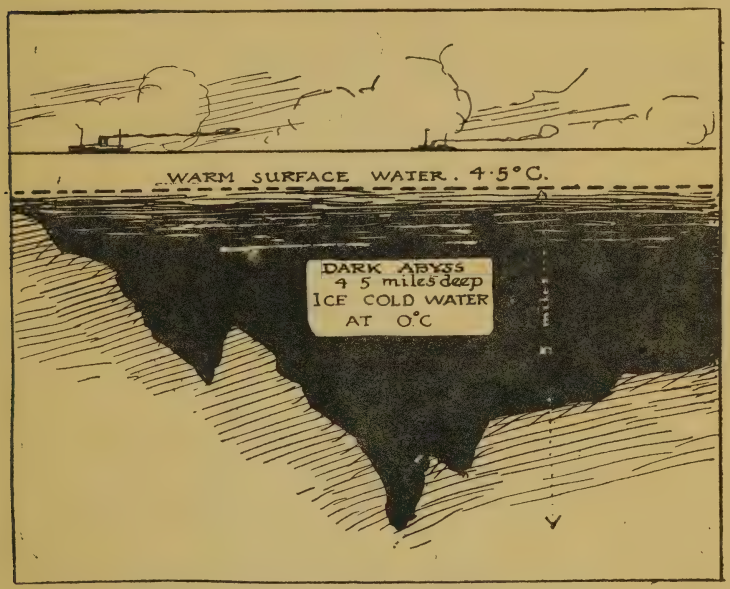


FIG. 15.—Temperature of the Water of the Sea.

of heavier. Consequently, water cooled below 4° C. floats upon the surface of water at 4° C., and if it is exposed long enough to the cold atmosphere, it will freeze and form a layer of ice *over the surface of the water at* 4° *C.* The case is somewhat different with sea-water, which contains much salt dissolved in it. Sea-water continues to contract right down to its freezing-point at about—2.8° C. Consequently, the more it is cooled the heavier it becomes. The coldest sea-water, therefore, sinks to the bottom of the ocean, and this is the

reason why the dark abysmal valleys of the sea are filled with water as cold as, and sometimes even colder than, melting ice. It is only when we approach the surface that the water becomes sensibly warm. A curious consequence of this fact is that ice in sea-water begins to form at the bottom—not always, because when ice is once formed on the surface it will extend from the edge of its previous surface. Still it is well known among Arctic voyagers and Baltic fishermen, that when the season is changing and ice is about to form, in the first instance it comes up in little plates or discs from the bottom. When the fisherman in the Baltic or Norwegian fiords sees these little discs coming up from the bottom, like so many jelly fish, to float on the surface, he at once, if his boat is at all distant from land, makes for land directly, for he knows that if he remains he might be frozen up in the course of a few hours.* Whether ice forms in the salt seas or in fresh-water lakes, one fundamental fact remains, and that is, that ice is lighter than water and consequently floats on its surface. Indeed, it would be a most serious matter if this were not the case. For example, if ice were heavier than water it would, when formed, sink to the bottom; hence in sharp winters ice would gradually accumulate at the bottom of our lakes and seas; the heat of the succeeding summer would merely warm the water on the surface without affecting the temperature of the water below a certain depth, because water is such a very bad conductor of heat. In fact water conducts heat so badly that it is possible to place a piece of ice (wrapped round with lead wire in order to make it sink) at the bottom of a long tube containing water, and then boil the water at the top without melting the ice at the bottom! Hence, as winter succeeded winter the layer of ice at the bottom of our seas and lakes would gradually increase in thickness until all our seas, lakes, and even the mighty oceans themselves, would be converted from top to bottom into vast masses of ice.

All that the heat of the summer could do would be to melt the superficial ice through a few feet, thereby converting

* Dr. Carpenter's "Science Lectures for the People," 2nd Series, 1870-71, pp. 116, 117.

the seas into vast shallow morasses, with deep crevices here and there. In winter all would be frozen over again. Nothing could live in such a sea. Fishes would be unknown except in regions that we now deem tropical. Our climate would be arctic in character. Northern Europe would be an unknown land, covered over with vast glaciers and perpetual snow; it would present much the same appearance that the cold, desolate continent about the South Pole presents to explorers at the present time. The sites of world-cities like London, Paris, Berlin, would be occupied by ice-clad plains swept by cold winds and snow-storms. The centre of civilisation would shift from lands like Europe and Northern America to tropical lands like India, Africa, and Central America, which, however, would under the new conditions enjoy a quite temperate climate.

Who would have thought that the apparently unimportant property that water possesses of slightly expanding when freezing would have exerted such an astonishing influence upon our world and on civilisation?

At the moment of freezing the water increases in volume and in so doing exerts a very great pressure. Now soils and rocks are all porous and suck up large quantities of water. A frost comes and this water freezes, forcing the particles apart. The soils on thawing are thus powdered. Water freezing in the innumerable cracks between rocks drives them asunder. Gradually, with each succeeding winter, the rifts in the rocks grow wider and wider, until ultimately the rock splits in pieces, and goes thundering down into the valley below. At Spitzbergen and on the coast of Greenland great rocky cliffs are being continually demolished from this cause.

Water under ordinary atmospheric pressures freezes at 0° C. But under great pressures it will not freeze even at low temperatures. Thus, if subjected to a pressure of 13,000 atmospheres water freezes at—18° C. Conversely, great pressures will turn ice into water. Thus if a mass of ice, cooled to a very low temperature and subjected to the very great pressure of 13,000 atmospheres, be allowed to gain heat, it melts when the temperature reaches—18° C. The in-

stant the pressure is released the water at once freezes again, for it is only the pressure which preserves the water in a liquid form below 0° C. These facts acquire a great importance in northern regions. The whole of the regions around the North and South Poles are vast snow-fields some miles deep. Think of falling into an abyss two miles deep! Yet there probably occur rifts and cracks in the ice which descend to such vast depths. These cracks form as the result of a slow but perpetual movement of the ice under its own weight; and this movement seems itself to depend upon the fact that under the huge pressure exerted by the ice above, the ice in the depths melts and the whole mass thus becomes mobile, flowing from the hills and mountains slowly down to the sea. These great rivers of ice are called "glaciers." They occur in all parts of the world where the mountains are high enough. The more rapid travel four feet in an hour, the slower ones only a few inches a day or perhaps a week. We must not think of these vast masses of ice as formless. No, every fragment of ice possesses a wonderfully intricate and beautiful internal structure, being composed of myriads of molecules all definitely arranged in space and all whirling, like little spinning tops, at a tremendous rate. This beautiful internal structure of ice may be revealed to the eye by allowing a beam of sunlight to pass through a block of ice by means of a lens. Suddenly there flashes into view throughout the interior of the previously apparently formless ice, a large number of little geometrical six-sided

FIG. 16.—Snow Crystals.

stars, partially vacuous because the ice contracts in volume when melting to water. The beautiful crystals seen when snow is examined under a microscope give further evidence of the wonderful internal structure of frozen water. A fragment of ice the size of a pin's head contains a million million million molecules all definitely arranged and rotating in parallel directions. Such a tiny speck of ice, therefore, contains a hundred thousand million times more molecules than there exist visible stars in the whole universe! How enormously vast a universe of molecules, then, must be one of the huge icebergs floating in the sea! And our wonder grows when we reflect that these icebergs, vast as they are, form only an insignificant part of the whole mass of similarly constituted ice which clothes our Poles eternally with a garment of dazzling whiteness.

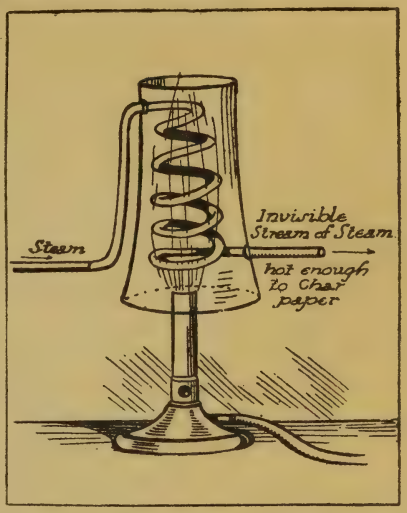


FIG. 17.—Production of Superheated Steam.

Under ordinary atmospheric pressures water boils at 100° C., passing into an invisible gas or vapour called steam. It is only when this invisible vapour cools below 100° C., that it condenses to a multitude of tiny drops of water. The white clouds which form around steam jets and which float in the sky are formed of these tiny drops. True steam is invisible. This may be shown by means of the following very remarkable experiment. A jet of ordinary steam from a boiler is passed through a copper pipe heated to a low red heat (Fig. 17). The issuing steam is so hot that it does not, like an ordinary steam jet, condense to a visible white cloud. Its temperature is so high that it cannot condense at all to the

droplets of water which form a steam cloud. Instead, it mixes with the air and then dissolves clear in it. Consequently, such a stream of steam is quite invisible. Its presence, however, may be made manifest to the eye by holding in its path a bit of paper. So fierce is the heat it possesses that the paper is seen to char as in a fire.

In many planets all the water is in this superheated gaseous state; and once upon a time it was also in this state upon our own earth, as we have already seen. Hence we see that although we always regard water as a liquid, yet, if we had happened to live under conditions somewhat different from those now reigning upon the earth, water might have been known to us only in the form of a gas or a solid, and we could not have failed to form entirely different notions of its properties from those that we now hold. For example, if the planets Jupiter, Saturn, and Neptune were inhabited by a race of intelligent salamanders, to whom a bright red heat was a pleasant degree of warmth, then, to these truly hot-blooded creatures water as a liquid would be quite unknown. For, the surface of these planets being probably red hot, they could only know it in the form of a gas, quite invisible to the eye, and presenting much the same properties to them as air does to us at ordinary temperatures.

The pressure of aqueous vapour or steam increases with the temperature. Thus at 0° C. it equals the pressure of a column of quicksilver 4.6 mm. high. At 100° C. it balances 760 millimetres of mercury, or the pressure of our atmosphere. At 370° C. the pressure of steam is 196 atmospheres, or 1⅛ tons per square inch! Now water boils when the pressure of its vapour equals the pressure on its surface. Water, therefore, can be made to boil at almost any temperature by merely altering the pressure on its surface. Thus, if the pressure on its surface is only 4.6 mm.—say the pressure inside the bell jar of a good air-pump—the water will actually boil at the temperature at which it freezes, viz. at 0° C., for at this temperature the pressure of steam is 4.6 mm. At 100° C. the pressure of steam just balances the pressure of the atmosphere at the sea-level, and this is why water under ordinary conditions boils at 100° C. At a temperature of 370° C. the

pressure of steam amounts to nearly 196 atmospheres. Consequently, when subjected to this great pressure water will boil at 370 ° C., that is to say, almost at a red heat ! Several important natural consequences arise from these facts. Thus down at the bottom of the ocean, where the pressure often amounts to over a thousand atmospheres, the water would not boil even at a low red heat. It could, therefore, rest upon a red-hot sea-bottom without explosively turning into steam. Again, on the tops of high mountains, where the atmospheric pressure is low, water boils considerably below 100°C. At the top of Mont Blanc it boils at 86.4° C. ; on Mount Everest it boils at about 70° C. Water boiling at this temperature would hardly cook an egg !

On a planet such as Mars, where the atmosphere is light and thin, water would boil at the temperature of the blood ; while on the moon, where the mountains jet up sheer into an absolute vacuum, water would boil below the melting point of ice ! Ice on the moon would sublime without melting, just as camphor does under ordinary temperatures and pressures.

We must now say a few words about the curious effect a high temperature produces on the properties of water. Let us imagine the reader to be transported for a short time to that early period of the world's history when the seas which now cover her were just beginning to be deposited. The atmospheric pressure at that time was hundreds of times greater than it is now, and consequently, the waters of those early seas would not boil, as they now do, at 100° C., but at a far higher temperature. The earliest seas of our planet may have possessed a temperature anywhere between 300-370° C. Indeed, at the present time many planets must exist which are covered with seas of such intensely hot water. The highly heated and compressed water which occurs deep down in the interior of the earth is in just the same condition now as the early seas of the earth were once.

Such highly heated and compressed water, however, presents properties entirely different from those usually associated with this useful and harmless liquid. Under such circumstances it becomes one of the most corrosive substances

known, acting in many ways like a strong acid such as diluted oil of vitriol. As we shall see in a later chapter such intensely hot and compressed water will dissolve metals like iron and zinc with effervescence, just as a strong acid will, evolving hydrogen gas.

Even such an insoluble substance as glass dissolves in it as freely as sugar in tea. It is just as well, therefore, that we do not live in such times, for we should certainly have had to do without such articles as glass tumblers and iron kettles! "At ordinary temperatures," says Geikie,* "water is a very weak base or acid. At 18° it is about 100 times weaker than silicic acid. But by increase of temperature the relationship of the two bodies is completely changed. At about 300° C. it is estimated that water and silicic acid are equally strong, but at 1000° C. water is some 80 times, and at 2000° C. about 300 times stronger than that acid. . . Water at 1000° and 2000° C. will act as a powerful acid."

There is nothing really very surprising in this when we remember that all liquids which are strongly acid at ordinary temperatures become quite neutral at low temperatures. A decrease of temperature reduces acid properties while an increase of temperature increases them. For example, the strongest mineral acids which we are acquainted with, such as sulphuric, hydrochloric, and nitric acids, all most intensely corrosive substances at ordinary temperatures, become at —105° C. quite neutral substances.

Water, in fact, is in just the same condition at ordinary temperatures as these acids are at low temperatures. All that is required in each case to bring out acid properties is an increase of temperature.

* "Textbook of Geology," p. 356 (1903).

CHAPTER VI

THE ELEMENT HYDROGEN

It is difficult to describe the further wonders of chemical changes without making the reader familiar with some of the substances which take part in them. We will therefore begin by giving a description of the simplest of all the substances known upon the earth, that is, the element hydrogen.

Nearly four hundred years ago the famous alchemist Paracelsus observed that when metals like iron or zinc were placed in sour or acid liquids, like vinegar or diluted "oil of vitriol," the metal gradually dissolved and at the same time bubbles of a gas were seen to rise through the liquid. This gas rose exactly like ordinary air, but was distinguished from it by the fact that it caught fire and burnt when a light was applied to it. On account of this it was known for long as "inflammable air," but we now know it is nothing but the element "Hydrogen." The apparatus usually used for preparing the gaseous hydrogen is shown in Fig. 18. The bottle A contains fragments of iron or zinc; acid diluted with water, say sulphuric acid, is poured down the glass funnel C on to the metal, and the gas as it comes bubbling up through the liquid is led off through the glass tube into the bottle B, which has previously been filled with water, and inverted over the same liquid contained in a basin. The gas bubbles up through the water and is thus easily collected. The mechanism of this action is chemically a simple one. All acids contain loosely held hydrogen, and indeed they owe their sourness and other distinctive properties to this fact. Many metals dissolve in acids and in so doing expel the hydrogen from the acid and occupy its place in the molecule. For example, in the case

of iron or zinc and sulphuric acid the chemical changes are expressed by the equations :

$$\underset{\text{Zinc}}{Zn} + \underset{\substack{\text{Sulphuric}\\\text{Acid}}}{H_2SO_4} = \underset{\substack{\text{Zinc}\\\text{Sulphate}}}{ZnSO_4} + \underset{\substack{\text{Hydrogen}\\\text{Gas.}}}{H_2};$$

$$\underset{\text{Iron}}{Fe} + \underset{\substack{\text{Sulphuric}\\\text{Acid}}}{H_2SO_4} = \underset{\substack{\text{Ferrous}\\\text{Sulphate}}}{FeSO_4} + \underset{\substack{\text{Hydrogen}\\\text{Gas.}}}{H_2}$$

This is an experiment familiar to the merest tyro in chemistry. Almost every schoolboy has prepared hydrogen at some time or other by this method ; yet how few of those who have performed this experiment dozens of times have realised the mystery and wonder of the process that is going on under their very eyes ? How few realise as they watch the zinc or iron dissolve in the acid and the countless bubbles of gas arising merrily through the liquid, that they are witnessing a veritable molecular catastrophe ? Yet this is so. As we have seen in a previous chapter all chemical reactions are to the atoms tremendous catastrophes. The liquid that we see in the bottle really consists of countless millions of tiny molecules, tiny planetary systems of atomic dimensions, each pursuing its own individual course in the liquid, a course so charged with events and changes that in the millionth part of a second, a span of time so small as to be absolutely beyond our consciousness, each one of these little molecules has lived through an age, has survived millions of collisions with other molecules, has been transformed, shattered and re-formed, thousands upon thousands of times. Each sulphuric acid molecule consists of a central sulphur atom to which are attached four oxygen and two hydrogen atoms, each rapidly swinging round a tiny orbit in the molecule, and when this system collides with the atoms of zinc or iron, the ensuing shock sends the rapidly moving hydrogen atoms flying off into space, and we see them arise as an innumerable number of tiny bubbles through the liquid, each bubble itself a vast array of billions of atoms of this gas. The metallic atoms take the place of the hydrogen atoms in the sulphuric acid molecule and thus produce the salts, zinc or iron sulphates. The action, however, is really much more complicated than this. It is attended with the

development of electricity and with other phenomena, which, however, we cannot stop to discuss here. Indeed, though the chemical equation expressing the change is simple enough, the real complexity of the process is probably immeasurably greater than anything of which we have any conception. The ceaseless collisions going on all this time between the sulphuric acid molecules and the zinc atoms naturally set up violent motions among the molecules,

FIG. 18.—Preparation of Hydrogen.

and this increased motion manifests itself as heat. The solution becomes quite warm to the touch.

Many other methods of preparing hydrogen exist, but we will mention no more than two. We saw in the last chapter that water contains hydrogen combined with oxygen. Now many metals will decompose water, combining with its oxygen and setting free its hydrogen. Some metals (such as sodium, potassium, calcium, etc.) do this at ordinary temperatures, but others, such as iron and zinc, require to

be heated. Thus if steam be blown through a red-hot pipe packed with iron filings, hydrogen gas will issue at the end of the tube and may be collected over water in the ordinary way. The water has been decomposed according to the equation :

$$\underset{\text{Iron}}{3Fe} + \underset{\text{Water}}{4H_2O} = \underset{\text{Black Iron Oxide}}{Fe_3O_4} + \underset{\text{Hydrogen}}{4H_2}$$

In the past disastrous explosions have been caused in iron smelting works by allowing the white-hot iron from the furnace to flow directly into water, either intentionally, with the object of cooling it rapidly, or accidentally. Large volumes of hydrogen have thus been evolved, which mixed with air forms an explosive mixture. The evolved gas coming into contact with the white-hot iron has then exploded, blowing scalding water and molten iron in all directions, and killing or wounding all who were near. Quite a short time ago an explosion due to this cause occurred in an iron works at Wolverhampton. A great blast furnace was in action and all was going on quietly when suddenly a thunder-like explosion took place underneath the mighty structure, and with a mighty roar there burst forth smoke and flame and flying fragments of fractured masonry. The molten metal at the bottom of the furnace had leaked into a small quantity of water flowing along a channel which discharged from the tuyeres, and the water, being instantly decomposed, produced a large volume of gas, which, exploding, shattered the bottom of the furnace and allowed no less than twenty-five tons of molten dazzlingly white-hot metal to rush tumultuously forth from the fractured furnace and demolish in its fury an adjacent building. Six men were working in the neighbourhood, and without a moment's warning they were hurled in all directions, while at the same time they were enveloped in a cloud of flying debris of white-hot molten steel, boiling water, masonry, and dust, and all were more or less badly injured. Indeed had the men happened to have been nearer to the furnace they could hardly have escaped total destruction.

At the present time masses of iron are cooled by spraying water upon them by means of a hose. In this case sufficient

gas is never evolved at one time to cause danger. In the case of impure zinc the same action takes places rapidly even in boiling water, according to the equation :

$$\underset{\text{Zinc}}{Zn} + \underset{\text{Water}}{H_2O} = \underset{\text{Zinc Oxide}}{ZnO} + \underset{\text{Hydrogen}}{H_2}$$

This fact may at first strike the reader as being of little interest or importance, and yet, so intimately is chemistry connected with our daily life, it has been attended with tragic consequences at least once. A few years ago some workmen while constructing a boiler carelessly left inside it some fragments of zinc, little dreaming that by so doing they would cause the death of so many fellow creatures and plunge so many happy families into mourning. In due course the boiler was hoisted upon a German war-ship and riveted down.

Some months afterwards the vessel went out on her trial trip. The hold was filled with busy stokers, and the great engines throbbed, driving the mighty vessel swiftly through the sea. All this time the water was heated in the boiler to an exceedingly high temperature and the zinc was dissolving rapidly in it, giving off a large amount of hydrogen gas. This mingled with the air in the boiler to form a terribly explosive mixture, and so all unknown to the men working around, the great boiler was gradually filled with the deadly gaseous mixture. Suddenly, without a moment's notice, with a blinding flash of light and a roar like an enormous thunder peal, the great boiler blew to pieces, killing or maiming all the men in the room and filling the vessel with a cloud of scalding steam. The cause of the explosion remained a mystery until some days afterwards the tell-tale fragments of zinc were found in the boiler. Thus we see that the forces of chemical affinity, which under control make so useful a servant, out of control make a terrible master. Hydrogen may also be obtained by passing an electric current through water which has been acidified with a little sulphuric acid. The electricity decomposes the water, hydrogen coming off at the negative and oxygen at the positive pole according to the equation :

$$\underset{\text{Water}}{2H_2O} = \underset{\text{Hydrogen}}{2H_2} + \underset{\text{Oxygen}}{O_2}$$

Solutions of many salts in water will decompose in much the same way. Indeed great industries, employing thousands or workmen and millions of money are founded upon this property of the electric current.

To the thoughtful mind there are few substances which arouse such interest as this invisible gaseous element. It is the lightest substance that occurs upon the earth (though probably there exist lighter elements in space) and as such has been the object of much attention and speculation. For many years it was believed that it formed the basis of all the elements, an idea first put forward by a chemist named Prout in 1815. He held that all the other elements were merely condensations of hydrogen atoms, and that consequently their atomic weights were all exact multiples of that of hydrogen.

The attempt to prove or disprove this idea has led to some of the most careful and magnificent research work that the world has ever seen. It occasioned the splendid atomic weight determinations of Stas, Dumas, Marignac, and others too numerous to mention. It filled chemistry with a mass of new data and inspired chemists with a dream of the chemical unity of all matter, an idea which, in its original form at least, has now been proved to be untenable. The atomic weights of all the elements are not exact multiples of that of hydrogen, although in many cases they are nearly so, and the nearness in the approach to whole numbers is far too close to be explained by accident or coincidence. The doctrine of the unity of matter is, of course, a very ancient one, dating back to the earliest dawn of civilisation in the East. Indeed it may ultimately be proved that

> "All things the world which fill
> Of but one stuff are spun."

Even to-day many chemists, with a considerable show of reason, believe in a modified form of Prout's hypothesis.

The mystery which surrounds this wonderful element is increased when we turn to the heavens and study the chemical constitution of the stars. We find that hydrogen has

an enormously wide distribution. We find it everywhere in space, no matter to what part of the sky we turn our eyes. We find it in every nebula, often in vast masses which stagger the imagination by their seemingly infinite extension. All stars contain it, some of the hotter ones being almost entirely composed of it. Our own sun contains an incalculably great quantity of it. On his surface may be seen vast flames of hydrogen which sometimes rush up in stupendous columns to the height of hundreds of thousands of miles.

FIG. 19.—Vast hydrogen flames observed on the sun's surface by Prof. Young in 1871. The flames were 100,000 miles long and 54,000 miles high. The size of the earth is shown for comparison.

In 1871 Professor Young observed some vast flames on the sun's surface which were 100,000 miles long and 54,000 miles high. In 1880 Langley saw some tower aloft to the height of over 350,000 miles ! Such flames are hundreds of thousands of times greater than our whole earth, and yet astronomers assure us that these are nothing to some of the flames which occur on many of the suns of space; for some of these are millions of times larger than even our own sun, gigantic as he seems to us, suns largely composed of hydrogen, of the very same hydrogen gas that we see arising from zinc and acid, but in a very different condition. For on such bodies the hydrogen is compressed by its own weight

until it is more rigid and solid than steel, and heated to such a high temperature that it glows and gives forth an immensely fierce light; there it is torn up by volcanic concussions of an unthinkably vast force, and hurled aloft in mighty flames to the height of a million miles and more! Even on our own sun hydrogen flames and torrents of heated gas rush in mighty cyclones over its surface at the rate of more than 400 miles a second!

Hydrogen is present always, not only when worlds are about to form, but also when they explode.

"In the youngest stars," says Le Bon,* "that is to say, the hottest, there hardly exists anything but a few gases, principally hydrogen; then as these stars become cooler, there successively appear the simple bodies we know, beginning with those of the lowest atomic weight. . . Spectrum analysis shows that these stars are at very different stages of evolution. Their past must be of fearful length, since geologists estimate the existence of our planet at several hundred million years. During these accumulations of ages unknown to history, the millions of stars with which space is peopled must have begun or ended cycles of evolution analogous to those now pursued by our globe. Worlds peopled like ours, covered with flourishing cities filled with marvels of science and of the arts, must have emerged from eternal night and returned thereto without leaving a trace behind them. The pale nebulæ (which as we have seen consist largely of hydrogen) represent perhaps the last vestiges of worlds about to vanish into nothing or to become the nuclei of a new universe. . . . We may ask ourselves whether the end of a universe by a sudden explosion after a long period of old age does not represent its most general ending. These abrupt annihilations manifest themselves in the sudden apparition in the heavens of an incandescent star, which pales and vanishes sometimes in a few days, leaving generally no trace behind it, or at most a faint nebula (which is always rich in

* Le Bon, "The Evolution of Forces," pp. 83-93. Published by Kegan Paul, Trench, Trübner and Co.; quoted by the courtesy of the publishers.

hydrogen). When the new star first appears, its spectrum, at first analogous to that of the sun, proves that it contains metals similar to those of our solar system. Then in a short time, the spectrum is transformed, and becomes that of the planetary nebulæ—that is, it only contains rays of a few simple elements (like hydrogen) some of which are unknown. It is therefore evident that the atoms of the temporary star have been rapidly and profoundly transformed. . . . These transitory stars, resulting no doubt from the sudden explosion of a world accompanied by the disintegration of its atoms, are not rare. Hardly a year passes without some being observed, either directly or by the study of photographic plates. One of the most remarkable was the one recently observed in the constellation of Perseus. In a few days it attained a brilliancy which made it the most brilliant star in the sky; but twenty-four hours later it had begun to pale, its spectrum was slowly transformed, and became, as before said, that of a planetary nebulæ—an evident proof, I repeat, of atomic dissociation. At the very moment when this transformation was taking place, photographs of long exposure showed nebulous masses round the star, produced no doubt by atomic dissociation, which rapidly left it behind at a speed of the order of light—that is to say, analogous to that of the Beta particles emitted by radioactive bodies when dissociating. The astronomers were, then, enabled to be present at the rapid destruction of a world."

The words in brackets are inserted by the author. Chemists and physicists are by no means agreed as to the correctness of this explanation of the facts given by Le Bon. There seems, however, little doubt that worlds do disappear suddenly, and in their place appears after a time a thin wisp of incandescent hydrogen and other light gases. So that hydrogen is undoubtedly connected with the great problems of the evolution of matter and of the universe. It is this fact which makes the study of this gas so supremely interesting. That hydrogen does actually occur in space, and that the spectroscopic observations of scientists are no mere chimerical theoretical deductions, we have a very tangible

proof; for a visitant from one of these hydrogen worlds actually fell upon our earth, and was analysed by Graham in 1867. This visitant was a piece of meteoric iron from Lanarto in Hungary. It was found to contain 2.85 times its volume of hydrogen. This shows that the iron had come from a planetary atmosphere containing hydrogen probably under a pressure far greater than that of our own atmosphere. Was this fragment a piece of some world which had been destroyed by a vast explosion or collision such as that which destroyed the star in Perseus? Had it been hurled with incredible force far from a flaming world into the depths of space, and after ages of wandering finally reached our world? Or was it but an aggregation of cosmic dust culled from all parts of the universe? No answer can ever be given now to these questions.

When endeavouring to estimate the amount of hydrogen which occurs in space we must remember that we are able to perceive this substance only when it is in a strongly excited and luminous condition. This is probably an entirely exceptional condition of matter. There must exist in space dark masses of hydrogen incalculably vaster than any of the luminous masses of which we are aware, and yet the quantity of hydrogen visible in the heavens is so great as to defy all calculation and all conception. No matter to what part of the heavens we turn we see it flaring there. This universal presence of hydrogen throughout the whole universe betokens that it plays some important part in building up the giant fabric. What this part is we do not know. As we have already mentioned, though no proof is forthcoming, it is suspected of being the fundamental element from which the others are derived. No doubt in the course of time a fuller light will be thrown upon this and other allied problems.

We need not look only to the heavens, however, to find hydrogen. We find it in plenty on the earth. Nearly one-ninth of the weight of all the vast masses of water on the globe are composed of this gas. How many billions of tons this amounts to, I am sure I cannot say. It must be at least a million billion tons. Hydrogen also occurs, though only in very small quantities, in our atmosphere.

The very small quantities which do occur have probably been belched out from volcanoes, as it is found in the gases evolved from them; but it also comes out of the earth in some places. Thus in the salt mines at Stassfurt it sometimes comes streaming forth in a very pure condition and under quite a strong pressure from cracks in the carnallite. It is found, too, mixed with other gases, in the gas wells which occur in Russia and America in oil-bearing districts. Curiously enough it is also evolved in very small quantities in the gases breathed out by plants. From all these sources it gets into the air. It has been suggested by Liveing, however, that it also diffuses in from the depths of space; for as we have just remarked very large amounts of hydrogen occur scattered in space, and as the sun with the planets rushes onwards with a velocity of nine miles a second towards an unknown destination, some of this hydrogen may well be caught in the earth's atmosphere. However, free hydrogen could never accumulate in very large quantities in the earth's atmosphere; for as Dr. Johnstone Stoney pointed out long ago, the attraction of gravity is not sufficiently strong to keep particles moving so rapidly as hydrogen molecules from gradually flying off into space.

Few chapters of science are more interesting, and at the same time few so rich in tragic incidents brightened only by the heroic courage and intrepidity displayed by the investigators, as that which tells of the attempts of man to attain dominion over the air and to explore its upper regions.

On account of its extraordinary lightness hydrogen gas has been largely instrumental in securing the success that has been achieved. The gas is nearly fourteen times lighter than air. It pours upwards through the air in much the same way that a cork rises through water. One cubic metre of hydrogen gas will lift 1.2 kilogrammes from the ground; or in English measure, one cubic yard of gas will carry a weight of three pounds.

It is no wonder, therefore, that this gas was employed for inflating balloons very soon after their invention. The first balloon ever filled with hydrogen gas ascended into the air at Paris on August 27, 1783. A young professor of

physics, Charles by name, having heard that the brothers Montgolfier had succeeded in causing balloons to ascend filled only with hot air, conceived the brilliant idea of using hydrogen instead which has an immensely greater lifting power. Assisted by the brothers Robert, Charles carried out his first experiment at the Champ-de-Mars, and on December 1 they undertook an aerial voyage. The arrangements devised by Charles are those still in use. The balloon is of strong silk coated with a layer of indiarubber varnish; its upper half is covered with netting, from which hang cords, to whose lower extremities is attached a wicker basket. In the latter are placed small bags of sand serving as ballast, and below it hangs a grappling hook. Ordinary coal gas has sometimes been substituted for hydrogen, although being much heavier it is not so effective.

The height to which such balloons will rise is very great. Thus Gay Lussac attained in 1804 a height of 23,000 feet, or over four miles; Barral and Bixio attained in 1850 a height of 24,000 feet, while Glaisher and Coxwell attained in 1862 the greatest height ever reached, that of between 36,000 and 37,000 feet, and at which the barometer only marked 7 inches as compared with 29.6 before starting. Strange indeed must have been the sensations experienced by these first voyagers. They had only to look over the side of the car to see the world stretching out far and wide below them at the depth of seven miles. Above them lay the open regions of space stretching away into all infinity. About them reigned a silence impressive and majestic, for no sound could come up through the thin air to tell of human activity so busy on the earth below, while the great empty depths of space could not carry sound from interstellar regions. Shut off in the lonely silence of the upper regions of the air, the weakness and insignificance of man must have been forcibly impressed upon them. To ascend to such great altitudes, however, is no pleasant feat. It is attended with danger to life and limb. Unpleasant sensations occur owing to the rarefaction and low pressure of the air. The elastic force of the gases of the tissues, having but a slight external opposing power, is apt to cause distension of the blood vessels and

bleeding of the nose. The respiration and circulation become quickened. Gay Lussac's pulse beat 120 to the minute, its normal rate being 66. Glashier fainted away and Coxwell's hands becoming numbed by the intense dreadful cold and lack of air prevailing in these high regions, he had to pull the cord controlling the escape valve with his teeth in order to descend to lower regions!

In an ascent made by Tissandier, Sevil, and Croce-Spinelli, the last two actually died in the balloon from want of air. These dangers are now somewhat obviated by carrying cylinders of compressed oxygen, which is cautiously respired when the supply of air fails.

Hydrogen gas is, like air, colourless, tasteless, and odourless. It burns with a feeble non-luminous flame, producing water:

$$\underset{\text{Hydrogen.}}{2H_2} + \underset{\text{Oxygen.}}{O_2} = \underset{\text{Water.}}{2H_2O}$$

Nevertheless the gas when mixed with the proper amount of air or oxygen will explode most violently, producing water. This may be shown by means of a very striking experiment. A thin glass flask is filled with a mixture of hydrogen and oxygen in the ratio of 2 : 1, and the mixture is ignited by means of an electric spark. Instantly there occurs a flash of light and a deafening explosion, and the flask is shattered into a fine dust (Fig. 20).

One pound of hydrogen in burning to water develops enough heat to raise 34,200 pounds of water one degree centigrade. This is an amount of heat so great that if directly converted into work it would hurl a ton weight into the air to the height of over two miles.

To liquefy hydrogen gas it must be cooled below its critical temperature, which lies as low as —241° C. The first to achieve this was Olszewski in 1884; but he only obtained hydrogen in a momentarily liquid state. Dewar was the first to obtain it in quantity, by its means giving us a glimpse of a strange cold world in which the temperatures prevailing are only a little above the absolute zero of temperature itself, and where matter is consequently in an almost heatless state. In this strange region of science

all substances pass into a changeless dead condition ; they are, so to speak, chilled into an everlasting sleep so far as the chemical activities of their molecules are concerned. Bodies such as strong acids or bases, which are distinguished for their chemical activities at ordinary temperatures, become as inert as nitrogen or carbon at ordinary temperatures. The only substance which still retains to some extent its chemical activities under these conditions is fluorine.

Matter in this intensely cold condition furnishes many interesting problems for experiment and speculation. It gives us a picture of the normal state to which the surface of a planet would attain in the depths of space, unless continuously warmed by a sun. Myriads of such cold planets must even now circle in silent darkness about burnt-out suns in the universe. Indeed every comet which rushes round our sun and then retreats into infinite space whence it came, experiences this degree of cold during the greater part of its journey.

All these wonderful results were achieved by first compressing hydrogen gas to about two hundred atmospheres' pressure, cooling it in liquid air, and then letting it expand continuously through a long tube. As it expands its temperature is progressively lowered until at last it reaches a temperature of —252.6° C., at which low temperature hydrogen gas condenses to a liquid. What a wonderful liquid too, this is ! It is as clear and mobile as the clearest crystal water and yet so intensely cold as to burn like fire ! A drop on the arm freezes blood and skin to a hard mass and produces a wound like the touch of a red-hot iron. It is a wonderfully light liquid,—far lighter than any other liquid with which we are acquainted. It is fourteen times lighter than water, so light indeed, that cork, wood, and oil sink in it like lead in water ! By evaporating this liquid an even more intense cold is produced, and finally, if the evaporation is rapid enough, the cold liquid will freeze, and become a solid ice-like mass, which melts at —258.9° C., only 14° from the absolute zero of temperature itself ! Recently by the same process Onnes has succeeded in liquefying helium gas, which boils at only 4.5° absolute, and by

evaporating this liquid matter has been cooled to within 3° C. of the absolute zero of temperature, the greatest degree of cold ever yet produced !*

FIG. 20.—Explosion of a Flask filled with a mixture of Hydrogen and Oxygen Gases. When mixed together in the ratio of two volumes of hydrogen to one of oxygen the mixture will explode with a deafening report when an electric spark is passed through it. Unless the glass vessel containing the gases is very strong it will be shattered by the force of the explosion into dust.

All the properties of matter change at these low temperatures. Steel and copper become immensely stronger than they are at ordinary temperatures. Many dyes lose their colour ; crystals such as uranium nitrate become strongly

* Onnes, Proc. K. Akad. Wetensch, Amsterdam, 1908, 10, 744 ; 11, 168.

electrified, shining like phosphorus in the dark and emitting electrical discharges. All life, motion and change, to which we are accustomed all our lives, and which is the product of molecular motion, becomes an impossibility. Matter chilled to such temperatures becomes as changeless as death itself.

"Liquid hydrogen," says Dewar,* "introduces the investigator to a world of solid bodies. . . . It may be safely predicted that by its means many obscure problems of physics and chemistry will ultimately be solved, so that the liquefaction of the last of the old permanent gases is pregnant now with future consequences of great scientific moment. . ." Speaking of the liquefaction of helium, now an accomplished fact, but at that time still the object of strenuous endeavour, the distinguished Scotchman says: "The descent to a temperature within five degrees of the absolute zero would open out new vistas of scientific inquiry, which would add immensely to our knowledge of the properties of matter. To command in our laboratories a temperature which would be equivalent to that which a comet might reach at an infinite distance from the sun would indeed be a great triumph for science. . . . The chemists of the future will find ample scope for investigation within the apparently limited range of temperature which separates solid hydrogen from the zero. Indeed, great as is the sentimental interest attached to the liquefaction of these refractory gases, the importance of the achievement lies rather in the fact that it opens out new fields of research and enormously widens out the horizon of physical science, enabling the natural philosopher to study the properties and behaviour of matter under entirely novel conditions."

As Dewar rightly remarks, even if the absolute zero of temperature were reached by the investigator, it is by no means certain that he would find the near approach of the death of matter sometimes pictured; for even supposing that all the heat motion was removed from the molecules this would not affect the tremendous motions going on within the atoms themselves. The atoms would still remain microcosms full of stupendous electronic motions and change,

* Address to the British Association, 1902.

the very existence of which was, until the advent of radium, entirely unsuspected, except by a few advanced thinkers.

We must now say a few words about the structure of hydrogen gas. The gas, when contained in a glass vessel, appears to be perfectly transparent and structureless. But this is entirely due to the coarseness of our eyesight. Could we but

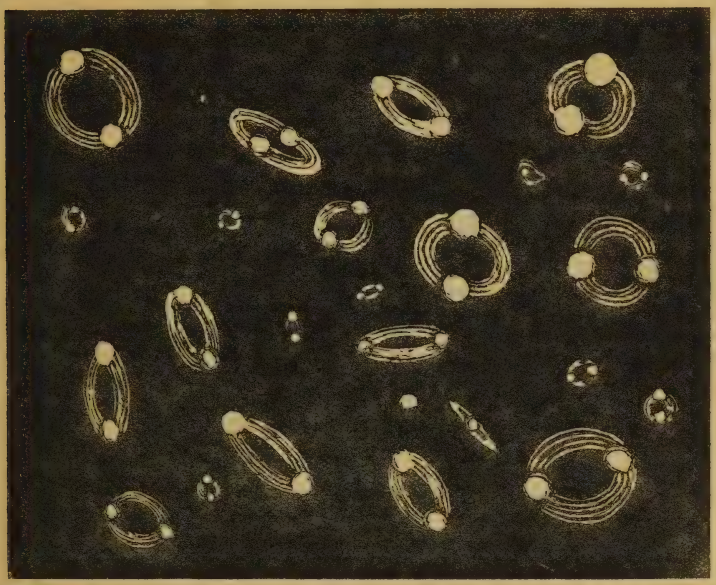


FIG. 21.—Imaginary Representation of the Structure of Hydrogen Gas. The gas consists of myriads of tiny molecules, each molecule consisting of two atoms revolving swiftly round each other. The molecules are at ordinary temperatures darting about with a speed of over a mile a second.

inspect the hydrogen through a microscope which magnified a few million times a wonderful unseen universe would flash into view. The gas would resolve itself into a swarm of countless myriads of fine particles flying about in our field of view, something after the manner of motes in a sunbeam, only far more swiftly. These are the hydrogen molecules. They are so exceeding small that the volume occupied by the smallest particle of dust visible to the eye contains

ample room to pack away a billion of them. In the gas as it occurs at ordinary atmospheric pressures the molecules are separated by distances which are many thousands of times their own diameters. They are, in reference to their diameters, as far apart in the gas as the solar system is distant from the nearest fixed star. If the whole structure of hydrogen gas was magnified ten thousand trillion times it would, as Fournier d'Albe pointed out, look very much like the stellar universe of which we form a part. A cubic foot of the gas when thus magnified would swell out into a vast universe as thickly peopled with atoms of stellar dimensions as the Milky Way is with stars.

The hydrogen molecule consists of two atoms which accompany each other on their journey through space, the one atom probably revolving around the other, much as the earth revolves around the sun or the moon around the earth. When we inspect some of this invisible gas imprisoned within a glass vessel it is indeed difficult to realise that the whole consists of myriads of molecules travelling at the speed of over a mile a second—faster even than a rifle bullet! Yet this is so; at 0° C. their average velocity amounts to 1,844 metres a second. Of course many of the molecules travel far faster and others far slower than this. The number given is the mere average of the different velocities.

The real hydrogen atom is very small, but by no means indefinitely so. Chemists have estimated their actual diameter as 0.2 millionth of a millimetre (2×10^{-8} cm.). Their actual weight is about 1.4×10^{-24} gram.*

If we were to magnify a volume of hydrogen as large as a hazel nut up to the size of the earth we would see each hydrogen atom in it about the size of a golf ball. How would it look? Probably absolutely unlike anything that we can imagine. All that we know about it is that it is not the simple structure that it was once thought to be. The chemists of the last generation were accustomed to think of it as a very small solid particle in shape something like our earth, or perhaps, of a simple geometrical shape, and composed of a simple material called "Hydrogen stuff"; but

* Meyer's "Kinetic Theory of Gases" (1899), p. 331.

recent discoveries have led to the conclusion that the atom itself is an extremely complicated structure, built up of about 2,000 smaller negatively-electrified particles, the electrons all revolving in complicated systems of circles about the centre of the atom, something after the manner of the planet Saturn and its rings of small asteroids.*

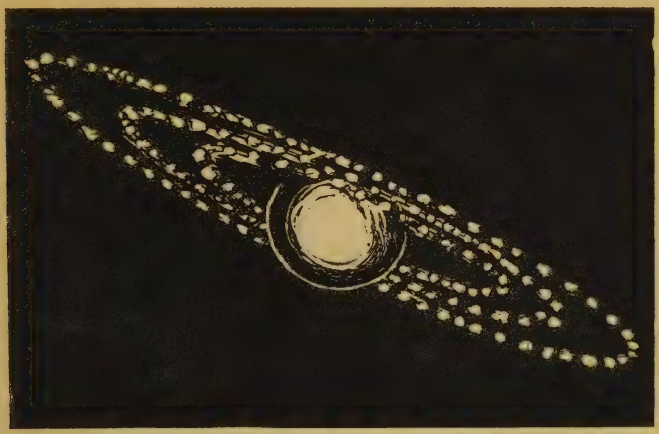


FIG. 22.—Structure of the Hydrogen Atom according to the Modern Electronic Theory. A central positively charged mass has arranged round it in a series of concentric rings many hundreds of negatively charged particles called electrons. The particles composing the rings are supposed to be rapidly rotating about the central mass. The whole system thus resembles somewhat the planet Saturn and his rings.

We thus see that the element hydrogen, usually regarded as such an uninteresting subject for study by one approaching it for the first time by means of one of the numerous elementary "cram" books of chemistry which cater for examinations that eat like a canker into our educational system, is in reality no dry or uninteresting subject. Rightly viewed it teems with problems still unsolved which are capable of providing food for thought and work to occupy a whole lifetime.

* See J. J. Thomson, *Philosophical Magazine* (6), Vol 7, p. 237 (1904). Nargarka, *Nature*, Vol. 69, p. 392 (1904).

CHAPTER VII

THE AIR

THE mystery of the air has fascinated poets and thinkers for ages. That we live at the bottom of a vast ocean of some invisible medium has, of course, been known since the earliest times of which we have any record. Such a fact could not have escaped the most unthinking savage. He saw the power of this medium in the cyclones and tornadoes which hurl mighty trees into the air like so many straws, and which overwhelm whole forests in swift destruction. The terrible powers of this medium led primeval man to associate it with invisible beings, gods and devils, who haunted the sky and empty spaces, and when they were angry dealt out death and devastation. The swift rush of the wind was to him the rush of mighty spirits, the wailing and moaning of it among the trees was caused by the wailing of lost souls in distress. Land and sky were full of horror and mystery.* Even to-day, in popular superstitution, spirits are represented as transparent, unsubstantial visions that arrive in an ice-cold draught, and vanish again into thin air, ideas which are the remnants of superstitions, thousands and thousands of years old, handed down in unbroken succession from time immemorial. What are the Greek gods, dwelling among the clouds, and revealing their powers in rain, hail, lightning, and thunder, but the remains of this air-worship? The warlike and hardy natives of the cold and gloomy North also referred all natural phenomena to gods living in the air. Thus the mysterious Northern Lights, which flared so gloriously in their skies, together with lightning, thunder, and earthquake, were all attributed to supernatural agency:—

* Even the highly-civilised Greeks worshipped the winds.

" The light thou beholdest
Stream through the heavens
In flashes of crimson
Is but my red beard
Blown by the night wind
Affrighting the nations !
Mine eyes are the lightning,
The wheels of my chariot
Roll in the thunder ;
The blows of my hammer
Ring in the earthquake."

These are the words put into the mouth of the great war-god Thor in Elgar's version of the old Norse legend of King Olaf. In the analogous southern superstitution the roar of thunder is the rumble of the wheels of God's chariot rapidly driven across the sky, and the lightning is caused by the cracks thus produced in the floor of heaven, through which inconceivable glory and splendour bursts forth for an instant.

Many among the untold millions of men who have passed away since human life, thought and civilisation began to flourish upon the earth must have pondered upon the mystery of the air ; yet during all this vast interval no one seems to have guessed its true nature until within a period so recent that it may be bridged over by the lives of two old men !

In very early times in Greece it was suspected that air is a thin, invisible form of matter having an atomic constitution. Vitruvius distinctly states that air has weight. We read of Aristotle making experiments on the weight of air by weighing a bladder when empty and when blown out, but, on account of the conditions of the experiment, with necessarily negative results. Then for near two thousand years intellectual darkness settled upon the world. The spread of a metaphysical philosophy which despised experiment, combined with the throes caused by the birth of new religions, crushed for many hundreds of years all aspirations of science, all gropings for light. The whole mighty fabric of ancient civilisation and intellectual life was overwhelmed by the inrush of barbarian warriors,

and the influence of the priests more than completed the ruin that the armies of Attila had begun.

In the fifteenth and sixteenth centuries Science gradually lifted up her torch of learning again, and with her advance our knowledge of the constitution of the air has gradually increased to the present day.

Air is matter. If possesses weight. Although invisible it is as truly material as a piece of stone or a brick. One cubic yard of air weighs about 2.2 lbs. A moderately sized lecture-hall will contain thirty to forty tons of it. If all the air in such a hall were frozen into one solid lump and dropped from the ceiling to the floor it would crush any one beneath into a formless pulp, and the thunder of the fall would be heard for many a hundred yards around. Think of the shock caused by the fall of a mass of thirty or forty tons of iron from such a height, and you will obtain a notion of the disturbance that would be caused by the fall of the equal mass of air contained in the room. The weight of the whole atmosphere amounts to 5,210 billion tons ; over each square yard of earth there lie between eight and nine tons of air.

If air is really so substantial a thing, why cannot we see it ? Why is it invisible ? The reason is that we are immersed in it. It surrounds us on every side. We can see water, but the fish in the sea cannot see it because they are immersed in it. Yet we can see bubbles of air in water, just as we can see drops of water in air. The fact of the matter is that confines and boundaries are necessary to vision. A body, before it can become visible, must exhibit some contrast of colour and transparency, some difference of light and shade, compared with surrounding objects before the eye can seize on these indications and the brain swiftly interpret them as due to the presence of a body. We never see a body. We only see, strictly speaking, differences of light and shade and colour from which, by a purely mental operation, we infer its form and attributes. The air presents to our eyes (if we except hot air ascending through cold air) none of these necessary indications of its presence, and so goes without perception.

In the same way, though we live immersed in and surrounded on all sides by a medium, the mysterious ether, which is thousands of times denser than granite and millions of times stronger than steel,* yet we are totally unaware of its presence, and we only infer its existence on the evidence of highly elaborate physical experiments.

Under this great ocean of mobile gas which we call the atmosphere, and for the most part by its agency, take place all the ceaseless changes and eternal circulation of matter which is going on so rapidly all over the earth's surface. In the absence of such a layer of gas the world would be a barren, changeless waste. Indeed, the atmosphere is at once the cradle and mother of all that is beautiful, of all that lives and moves upon the surface of this fair green world of ours. Though its commotions sometimes terrify us by their violence and bring death and destruction in their train, yet, as a whole, it deals gently with us. Few realise, for example, how well it protects us from the awful cold of space. Outside the world a temperature of nearly -273°C. prevails; and yet even in the coldest and darkest of Arctic nights, when the sun ceases to warm the surface of the earth for months at a time, the temperature never falls to more than a few scores of degrees below the melting point of ice; still in the hours of a single night there is ample time for the rocks and soil to radiate away nearly all their heat and sink to such a state of cold as would speedily bring all animal life upon the world to a close.

Why, then, does this not happen? The reason is that the atmosphere, like a warm blanket, encircles the earth and preserves us from this death-bringing frost. The atmosphere, in fact, possesses the same properties as a glass hot-house. It allows luminous rays of light and heat from the sun to reach the earth and warm its surface, but it will not allow dark heat rays, such as come from a kettle of boiling water, or a mass of sun-warmed earth, to escape again into space. It therefore stores up the heat of the sun and protects the surface of the earth from the evil of a too rapid cooling, in

* Sir Oliver Lodge, "The Ether of Space," 1909.

much the same way that an overcoat keeps our bodies warm on a winter's day.

The atmosphere also protects us from the awful artillery of heaven. The swiftest of our bullets fly through the air with a velocity of less than half-a-mile a second; yet in the empty depths of space rush countless myriads of iron meteorites—ranging in size from that of a microscopic grain of dust to that of a great mountain—flying silently through the frictionless ether with the stupendous velocity of from twenty to a hundred miles a second. If our atmosphere ceased to shield us they would rain down night and day upon the earth, striking its surface with terrific force, shattering the stoutest structures, and plunging for hundreds of feet through the hardest rocks. When we consider that a projectile from a modern twelve-inch gun, flying with a velocity of about a third of a mile a second, will crash through a foot of hardened steel as through a piece of paste-board, we can form some idea of the smashing force of these heavenly projectiles which, travelling hundreds of times faster, possess, weight for weight, an energy hundreds of thousands of times greater than any earthly missile. Strange as it may appear, however, at first, it is their very speed which preserves us from them; for, plunging into the atmosphere with such velocities, they encounter a terrific resistance. The friction causes them to become white-hot, and they burn away or shatter into a fine dust long before they reach us. The sudden blaze into splendour and the slow-moving trail of glory which marks the passage of a meteor across the sky announces at the same time the end of one of these heavenly projectiles.

Meteors have been observed to inflame at a height of 100-125 miles. Consequently quite an appreciable amount of air must exist even at these high altitudes. Arrhenius estimates the average height of the atmosphere as 250 miles, and some authorities extend it to over 500 miles. However this may be, the quantity of air and consequently its pressure, rapidly diminishes as we ascend the atmosphere.

Thus at a height of merely 4,296 metres (at Potasi) the pressure is only 0.62 that of the air at the sea-level. Glaishier

found in his balloon ascents that at a height of between six and seven miles the atmospheric pressure had sunk one quarter of its value at the sea-level. At fifty km. (31 miles) the pressure is only 0.3 mm. compared with 760 mm. at the sea-level, while at the height of 100 km. (62 miles) the pressure sinks to 0.02 mm. No further away than sixty miles above us, then, there reigns a vacuum as perfect as that producible by many air-pumps. A man suddenly ascending to such heights would die in convulsions. The instantaneous release of the pressure that our bodies supports (15 pounds on the square inch, 14 tons over the whole adult body) might cause internal blood vessels to give way and blood would come pouring through the ruptured walls into the brain, nose, eyes, and ears ; and yet, for hundreds of miles above this, the atmosphere still exists. " Above us," says Trowbridge,* " there extends a vast unexplored space far more interesting from a scientific point of view than the icy regions around the North Pole. No one can ever reach the limit of the upper regions of the air and live, unless he carries with him air to breathe and fuel to warm him ; for at the paltry distance of ten miles above the earth the air is too thin to support respiration, and the thermometer would register far below zero. It would be a region of perpetual snow on a peak of the earth if it should rise to such a height. A person in a balloon would not hear a friend in a neighbouring balloon, even if they were near enough to shake hands. There would be no medium for the propagation of sound waves."

Yet these upper regions are neither structureless nor motionless. Every part of this space is in a state of intense and complex circulatory movement. In them mighty winds rush perpetually with a speed of seventy miles and more an hour. The atmosphere has been compared to a vast machine kept in motion by the heat of the sun's rays. The whole of it has been moving thus for countless ages, and the different air-currents continually rushing through it form a vast mechanism of enormous complexity, the thorough exploration of which will occupy man for centuries to come. The

* *The Forum*, (1898), Vol. 26, p. 561.

mystery and wonder of the regions of the upper air is increased by the fact, brought to light by modern researches, that it is the seat of great electric currents, which, according to Trowbridge, sweep around the whole earth. It is certain that the rarefied air of these high regions conducts electricity almost as well as the best metallic conductors. It is equally certain that the sun has been for countless ages blowing a stream of negatively charged particles into the upper atmospheric regions. These are deflected in a series of electric currents towards the magnetic poles of the earth and, arriving in northern regions, crowd together and give rise to those wonderful natural electrical displays known as the Aurora Borealis, whose flashes and streamers of violet, green, and crimson light were long ago likened to " burning spears," and gave rise to the notion that

> " Fierce fiery warriors fight upon the clouds,
> In ranks and squadrons and right form of war."

The origin of the enormous volumes of gas which form our atmosphere has been for centuries a matter of active discussion among the learned. It is now believed that the atmosphere is nothing more nor less than the remains of that primeval fiery nebula from which the earth, sun, and solar system were evolved. Originally the whole was in a gaseous state, but in time the temperature of that part of the nebula from which our world condensed fell to such an extent that the more involatile heavy constituents were deposited in its central regions in a liquid state, and in time became covered over with a solid crust, thus forming the body of the earth. The more volatile gases and vapours remained behind, however, and the atmophere is merely those portions of the nebula which the present temperature of the earth's surface is sufficient to maintain in a gaseous state. Thus we see that the process of condensation of the nebula is by no means completed. In future ages, as the temperature of the earth slowly sinks, the gaseous air will be deposited first in a liquid and finally in a solid form, and it is only when this final stage of evolution is reached that we can regard the fiery earth-nebula as completely condensed.

It is a curious thought that the very wind which rushes in

our faces as we walk along the streets possesses an antiquity before which the oldest hills, and even the oceans, are things of yesterday. This wind began to blow at a time when the earth was "without form and void," a mere expanse of gas, and ever since that distant time it has never ceased to move; and for countless ages to come, day in, day out, it will continue to rush until it sees the sun decline from bright yellow to dull red, and finally sink amidst the gloom of the blackest night into darkness. Then, and not till then, will the atmosphere cease from its long race of ages and condense into solid matter like the rocks around us.

Air is a mixture of various gases. By far the greater part of its bulk consists of the two gases, nitrogen and oxygen, in the proportion of about four to one respectively. The active constituent of the air is the oxygen which allows bodies to burn. The nitrogen is a dead, inactive substance which will not support combustion or respiration. The proportions of the other gases air contains is small. We give here a table of its constituents taken from the most recent and accurate modern researches :—

TABLE.

One cubic metre* (100 litres) of dry air consists of

780.3	litres of	Nitrogen	gas weighing	975.80	grams.
209.9	,, ,,	Oxygen	,, ,,	299.84	,,
9.4	,, ,,	Argon	,, ,,	16.76	,,
0.3	,, ,,	Carbon dioxide	,,	0.59	,,
0.1	,, ,,	Hydrogen	,, ,,	0.01	,,
1000	litres			1293.00	grams.

Besides this there occur the following traces of rare inactive gases which have been recently discovered :—

0.015	litres	Neon	weighing	0.01339	grams.
0.0015	,,	Helium	,,	0.00027	,,
0.0015	,,	Krypton	,,	0.00018	,,
0.0000006	,,	Xenon	,,	0.00003	,,

* One metre = 39.371 inches. 1 lb. = 454 grams.

There also exist small traces of ozone, ammonium nitrite, and nitrate, sulphuretted hydrogen, micro-organisms, dust, etc., etc.

An illustration suggested by Graham will make these proportions clearer.

He imagines the air to be suddenly divided by magic into its components, arranged in non-mixing layers in the order of their specific gravities. Then we would have resting upon the surface of the earth the following layers, one upon the other :—

Water (liquid)	5 inches.
Carbon dioxide	13 feet.
Argon	90 yards
Oxygen	1 mile
Nitrogen	4 miles.

Of course, this would be on the assumption that these gases were compressed so as to be under normal atmospheric pressure throughout.

The amount of water spread through the air in the form of an invisible vapour varies pretty widely. One hundred volumes of air contain on an average 1.3 volumes of aqueous vapour. This forms only 0.84% of the weight of the air. A cubic metre of air contains about ten grams of water vapour—a small amount, you will say, at first sight. Yet if we consider the whole immense bulk of the atmosphere the amount of water thus held in it in the invisible form of vapour is enormous. It amounts to nearly fifty billion tons! This is enough water to form a lake one mile deep and covering 12,000 square miles of land!

This invisible gaseous water exerts an enormous influence upon the climate of our world. If it were all removed the average temperature of the atmosphere would fall by nearly 20° C., and consequently the greater part of the earth's surface would be converted into a vast ice-waste such as prevails within the Arctic circle! The reason is that water vapour is transparent to luminous radiations from the sun, but opaque to non-luminous. It will let the sun's rays reach the earth and warm it, but it will not let the dark heat rays which then begin to be emitted by the warm earth to escape

into space. They are nearly all caught by the aqueous vapour and carbon dioxide in the atmosphere, which thus keeps up the general temperature all over the earth's surface.

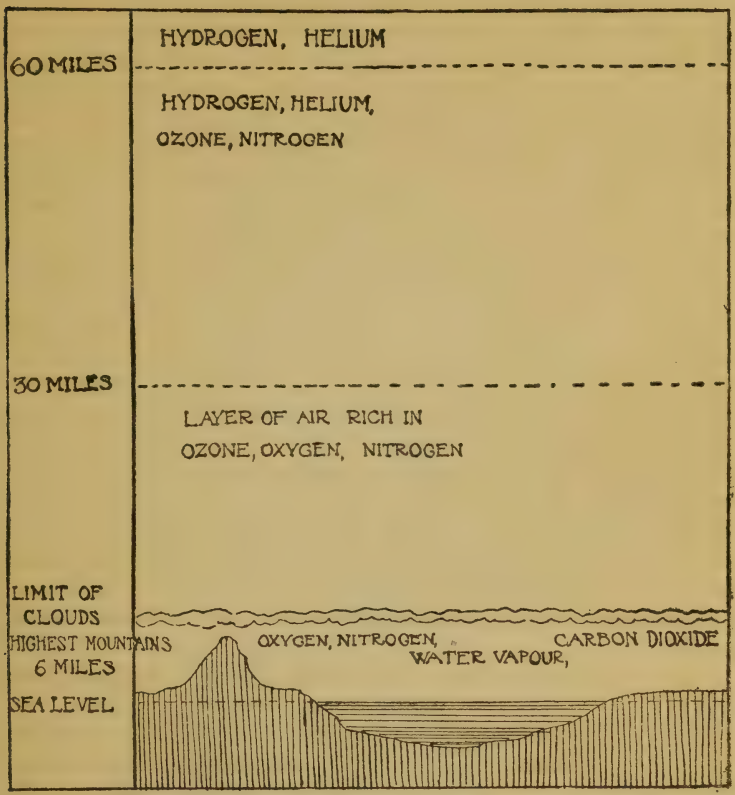


FIG. 23.—A Section through the Earth's Atmosphere, showing how its composition alters as it goes upwards.

Water vapour is much lighter than air. It weighs only 0.62 times that of an equal volume of dry air. It is consequently about as light as the coal gas used for filling balloons. This lightness causes the vapour-laden air to rise upwards into the cold upper regions of the atmosphere, and there the vapour condenses to tiny drops of visible water, which form

the white clouds which float in the sky. This is the reason why clouds usually occur far above the surface of the earth. Notice now how the apparently most insignificant scientific fact is fraught with world-wide consequences. For example, if water vapour had happened to be heavier than dry air, the moist air would never leave the earth's surface at all, and what an immense difference this would make in our lives! Our eyes would never behold bright gleaming sunlight and blue summer skies. We should live for ever in a fog denser than any London fog. We should be enshrouded in a pall of white mist heaped up thousands of feet above us, which would shut off from our eyes all the beauty of rolling landscape, all the grandeur of hill and dale. Under such conditions we could have had no Turner, no Constable, no David Cox, nor De Wint. Everywhere gloom, dampness, and monotony would prevail. Although we could hear from afar the thunder of the Niagara Falls or the roaring of the waves upon the sea-shore, our eyes could by no possibility penetrate the dense rolling fog which hid these majestic sights from us. We might possibly be ignorant of their very cause! The great waters of the earth, covered as they would be with vast masses of impenetrable fog, would remain gloomy and unknown regions, full of mystery and horror. Indeed it is doubtful whether, under such circumstances, man would ever have developed into a civilised being at all.

The amount of carbon dioxide in the air, though small (0.03 per cent.), is of great importance, since from this substance is obtained all the carbon of animal and vegetable life. The amount of it varies considerably as regards locality, being greater over great towns than in the country, and greater in the country than over the sea. It appears to be somewhat more abundant at a certain distance above the earth (0.033 per cent.) than on the earth's surface (0.029 per cent.). The reason of this is that volcanoes and tall chimneys are continually sending up vast currents of the gas high into the air, while plants are feeding on it and continually withdrawing it from the lower regions of the air. The people of the earth evolve in their

breath about one and a half million tons of this gas daily, but far greater quantities than this are produced from other sources, such as the decay of vegetable and animal matter, from fires, volcanoes, and earth fissures. There will be more to say about these matters when we come to deal with this gas in a later chapter.

The small amount of ozone in the air also varies widely. Near the earth's surface, especially near the air of towns, it seems to disappear entirely; but as we ascend the atmosphere the amount rapidly increases. On the top of high mountains the amount has risen to four times the amount found in lower regions. Doubtless at still higher levels, where great cold and low pressure favour its production, and where great currents of electricity stream and the action of the ozone-producing ultra-violet light of the sun is at a maximum, the proportion of ozone must be much greater. Indeed it has been suggested that the greater part of the oxygen of the air is in these regions converted into ozone, and that the tiny traces of this gas which exist in lower regions must have filtered down from above.

The lightest gases of the atmosphere, which are continually exuding out of the earth into the air, naturally ascend slowly but surely to the highest regions. And thus it comes about that at the height of 100 km. (62 miles) the atmosphere consists entirely of hydrogen (99½ per cent.) and helium ½ per cent.* We know this, not only from theoretical considerations, but also from observed facts. For example, when meteors flash into visibility at the height of a hundred miles the spectrum of the light they send out show that they are rushing through an atmosphere of hydrogen and helium.

Consequently if a mountain projected to this height into the air, and supposing that the difficulty of the rarefaction of the air at such an altitude was overcome, it would still be quite impossible for any animal to live even for a minute in the air at the summit. For here there would exist no free oxygen for the animal to breathe, and it would die of suffocation. In air of this composition, even if highly compressed,

* Erdmann, "Lehrbuch der Anorganischen Chemie," pp. 237 (1906). Dewar, "Address to the British Association," (1902), p. 40.

a candle would not burn, and coal and paper would be as incombustible as brick or stone!

It is very remarkable, however, that a heavy rare gas, krypton by name, should be observed to send forth light at the height of over a hundred miles, as is shown by an examination of the spectrum of the Aurora Borealis.

For the gas has an atom 81.2 times heavier than that of hydrogen, and so would not be expected to accumulate in such high regions.

The upper expanses of the air thus present many mysterious problems for solution, and we are only just beginning to learn something of its hitherto unsuspected wonders.

The air appears under ordinary circumstances quite invisible and structureless. But a single beam of bright sunlight streaming through a crack into a dark room teaches us otherwise. We see that the air is filled with a countless multitude of tiny dust particles in ceaseless motion. Over each great town this dust lies like a veritable sea; but it is present, though in greatly diminished quantity, at the greatest heights to which the atmosphere ascends. Whence comes it? Near the earth's surface it is the finely-powdered soil, grains of sand from the sea-shore, and salt from the sea-spray, mingled with the tiny bodies of myriads of useful and deadly bacteria, all swept upwards by wind and air currents, and kept suspended in the atmosphere by reason of their extreme minuteness.

In the highest regions of the atmosphere the explanation is otherwise. The dust there, descending in a steady stream age after age upon the world's surface miles below, comes from without the limits of the atmosphere. It is cosmic dust. For every star in this great universe of ours, every sun, and almost every planet, visible and invisible, is blowing ceaselessly into space a stream of tiny dust particles. With every volcanic explosion that takes place upon this earth a cloud of volcanic dust ascends to heaven, and some of it is hurled right away into space. On the sun, and on the millions of similar bodies which shine in the sky at night, hundreds of such explosions, vaster far than the mightiest dynamite explosion ever produced upon this earth, take

place each second all over their surfaces; and with each of these there fly off into space hundreds of tons of this dust. It has been estimated that the sun in each year loses in this way three hundred thousand million tons of dust, and the earth gains in the same time interval no less than twenty thousand tons of it.

Since this has been going on for eternities of time throughout all space, the whole universe, as far as the greatest telescopes can plunge into its vast abysses, is full of this dust. Indeed it is possible that most of the matter now bunched together in great globes like our sun or earth has once circulated through space as a fine dust, and will, in the course of time, so circulate again, not once but many times. The reason why the suns do not all evaporate away into such dust is because they receive in each instant as much as they throw out. The universe has in this respect attained equilibrium. This dust, once clear of sun or star, is often driven right away from it by the radiation pressure of light. It is thus streaming through space often with velocities of thousands of miles a second. Ultimately, these dust streams aggregate to form meteorites (and at a later stage comets, nebulæ, suns and planets). Each meteorite which comes rushing into our atmosphere is again resolved by the immense frictional heat into its primeval dust, which then again falls upon the earth.

Most of this dust is electrified. It carries negative electricity to us from the sun and causes those wonderful electrical discharges which astonish the dwellers in the Arctic and Antarctic regions. All the electricity circulating in our atmosphere, rushing in every flash of lightning, or eddying in every slow-moving fire ball, comes from afar, from the sun millions of miles away, and in part from stars in regions so remote as to be for ever invisible to human perception.

This dust is of enormous importance to us. On it, and by its means, the invisible water vapour in the air condenses to clouds and rain. If the air were absolutely dust-free probably the whole of the land would be a rainless and waterless desert; for it has been proved that without a

nucleus of some sort aqueous vapour will not condense at all to visible drops.

When we watch the countless motions of these little dust particles the mind suddenly realises that the air is far more complex than we had previously thought. It was this dust that suggested the atomic theory to the thinkers of old in India and Greece. The Indian philosophers imagined that we should merely have to divide each dust particle into six parts in order to reach the atoms. We know now, however, that the divisions must be carried out perhaps hundreds of millions of times before this result would be reached. In fact, if we could magnify the air a hundred million times, and thus bring its actual molecules into the bounds of visibility, its complexity would appear almost inconceivable. Each dust particle would swell into a vast galaxy of hundreds of millions of closely packed atoms about the size of walnuts, all bunched together and each in swift and incessant movement. Around it and colliding with it in all directions would stream countless millions of air molecules rushing with an average speed of 485 metres a second. Nor would the air molecules be all alike. If we could, like Alice in Wonderland, take up our standpoint on one particular molecule and watch the others stream past, we would see that out of every ten thousand molecules which swept by no less than 7,800 were nitrogen, 2,100 oxygen, 94 argon, 3 carbon dioxide, and only one hydrogen. The other gases are present in such a small quantity that if we imagined the air molecules to pass at the rate of one a second, we should have to watch night and day for nearly five years before we obtained a glimpse of a xenon molecule, and eight months before a krypton molecule came in sight. Three months would suffice for a helium molecule, and a week for a neon molecule to come past. Yet in a single minute no less than 48 nitrogen and twelve oxygen molecules would have passed. We may obtain some dim idea of what would be seen under such conditions by looking at the whirling snowflakes falling incessantly downwards in countless numbers in a heavy snowstorm. Only we should have to imagine each snowflake to be travelling about 500 yards a second in order to

make them conform to the velocities of the air molecules. They would thus drive past like bullets, or rapidly-moving hailstones.

Now think that in one cubic centimetre of air, that is to say half a thimbleful, there are no less than sixty trillion molecules. Imagine then how many exist in our whole atmosphere which extends for miles in every direction! The number is incomprehensibly vast! Think now, of the mighty air currents flowing in different directions, of the great winds and storms. The winds are but mighty torrents of untold myriads of molecules flowing all in one direction. To an insect so small as to be capable of inhabiting a single air molecule in the same way that we inhabit the earth, the myriads of molecules sweeping past and onwards in the wind, in countless and endless numbers, would present much the same appearance, though far more numerous, that the streams of stars in the Milky Way present to the Earth's astronomers. What is the object, what the end of this appalling complexity? For each of these countless molecules has an individuality and a life of its own. Each speeds on its way governed by forces with as much precision and exactitude as the planets which swing in their orbits round the sun.

Our grandfathers would have been much astonished if they had been told in early youth that they would live to see the invisible air in which they lived reduced to a clear sparkling liquid which boils on ice, freezes pure alcohol, and burns steel like tissue paper! They would perhaps have been even more astonished if they had been told that in their time men would even succeed in freezing the air, in turning it into a white solid ice-like mass, so intensely cold that its touch burns like the fiercest fire! We propose to lay before the reader a brief account of the magnificent modern researches which have led to these wonderful results.

"To produce liquid air in the laboratory," says Dewar, "is a feat analogous to the production of liquid water starting from steam at a white heat, and working with all the implements and surroundings at the same high temperature. The problem is not so much how to produce intense cold as to

save it when produced from being immediately levelled up by the relatively superheated surroundings." After a century of continual effort human perseverance and endeavour have at last succeeded in overcoming these difficulties with the result that liquid air may now not only be produced in gallons at a time, but it may be kept for weeks in wonderful heat impervious vessels first introduced into general use by Dewar.

The principles involved in the liquefaction of air are simple enough. When a gas is compressed heat is evolved. Conversely, when it is made to expand freely and suddenly cold is produced. The lower the initial temperature of the gas the greater is the cooling effect produced by its expansion. Linde, Hampson and Tripler have all constructed machines for liquefying air based upon these principles. A diagram, that of Linde's machine, is given in Fig. 25. Through a strong tube ABCD air enters at ordinary temperatures but under the great pressure of 200 atmospheres. By suitably regulating the throttle valve R the compressed air is allowed to expand suddenly at C into the chamber NO, where the pressure is only twenty atmospheres. A great cooling effect is thus produced, and the air thus chilled passes back up the tube EFGK, and thus cools further the incoming air in the pipe ABCD. This chilled air of the inner tube then expands as before at C, with a still further lowering of temperature, and the still colder expanded air thus produced continues to pass up the outer tube and chill more and more the incoming air until at last its temperature is lowered to such a point that the sudden expansion at C liquefies it to a colourless fluid which rapidly collects in the chamber NO. The cold air escaping through the outer tube EFGK passes again into pumps where it is compressed again to 200 atmospheres, cooled by water coolers to ordinary temperatures (for it is strongly heated by the compression) and again allowed to enter through the inner tube. Seeing that an extremely low temperature prevails in all these tubes they must be most carefully preserved from external heat by packing in non-conducting wool or feathers. Also in the actual machines the parts of the tubes shown in the diagram between B and E are hundreds of yards long, and, in order to save space,

FIG. 24.—Tripler's Apparatus for Experimenting with Liquid Air.

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are coiled spirally. The commercial separation of liquid air into its constituent gases, oxygen and nitrogen, will be dealt with under the heading, "Manufacture of Oxygen Gas."

The problem of keeping this liquid air when obtained was a very serious one. It is similar to the problem of keeping

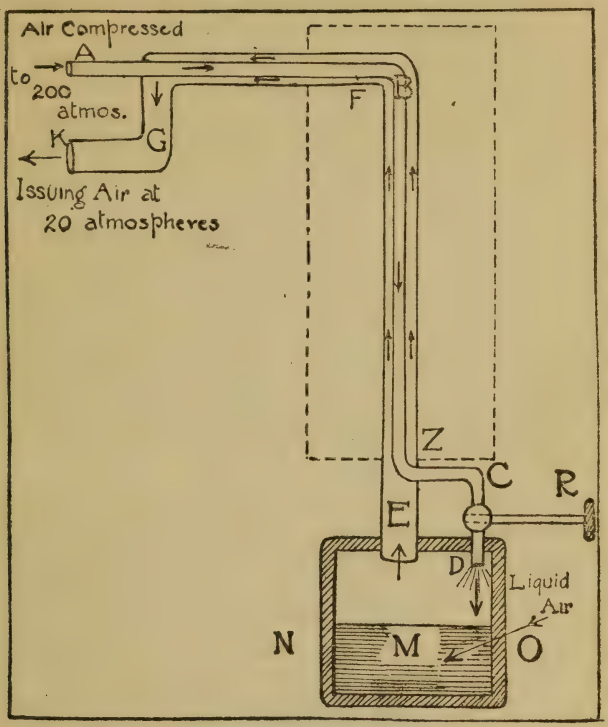

FIG. 25.—Linde's Apparatus for Liquefying Air.

water from boiling away when surrounded on all sides by a white hot furnace. Dewar solved the difficulty by placing it in a doubly walled vessel, the space between whose walls had been previously carefully evacuated. The empty space forms an almost perfect insulation and in such vessels liquid air may be kept for weeks at a time. It may even be transported in such vessels for thousands of miles with but little

loss, although surrounding the liquid air on all sides is a medium almost red hot in comparison to it. Think, too, of the curious possibilities that the invention of these heat impervious "Dewar Flasks" opens out. Centuries hence, when the world's supply of coal is almost exhausted, and firing has become immensely dearer, such vacuum-jacketed vessels may come into general use for keeping liquids hot or cold, and even for making the walls of houses impervious to heat or cold. Instead of making hot tea several times a day, the family may in future times make it, perhaps, once or twice a month, and store the hot fluid in one of these vessels and serve it out boiling hot from day to day as required!

Liquid air is nearly as heavy as water and quite as clear and limpid. When seen in the open air it is always muffled in a dense white mist that wells up over the edge of the vessel in which it stands, and rolls along the floor in beautiful billowy clouds. It presents, in fact, much the same appearance as a mass of boiling steaming water. The intense cold of the liquid causes the moisture in the surrounding air to condense as clouds, and it is this which gives rise to the curious phenomenon.

No other substance in the world, excepting liquid hydrogen and liquid helium, is as cold as liquid air; and yet the hand may be dipped into it fearlessly! The sensation is only that of a soft cushion about the hand. Such it really is. The hand is so hot in respect to liquid air that a layer of vapour surrounds it and prevents the liquid from coming into actual contact with the flesh. However the hand must not be allowed to remain in the liquid for more than an instant, for if the liquid were actually to touch the flesh a severe injury like a burn would result which sometimes takes months to heal. Even a few drops retained on a man's hand will sear like a white-hot iron. For this reason liquid air has been used in surgical cases where cauterisation is necessary. It is stated to eat out diseased flesh quickly and rapidly. Indeed a well-known New York physician seared out a cancer by its means and entirely cured a difficult case. The early hopes entertained of its use in this direction do not, however, seem

to have been realised. It is curious to note that over 200 years ago, the burning effect of great cold revealed itself clearly to Milton's poetic imagination. In his "Paradise Lost" he thus grandly describes the Land of Absolute Zero :

> "A frozen continent
> Lies dark and wild, set with perpetual storms
> Of whirlwind, and dire hail which on firm land
> Thaws not; but gathers heap, and ruins seem
> Of ancient pile : all else deep snow and ice.
> . . . . . The parching air
> Burns frore, and cold performs the effect of fire."

The grandest poetic and scientific imaginations are closely akin, and consequently, whatever science may unveil, the chances are that in the world's best poetry will be found hints of every discovery.

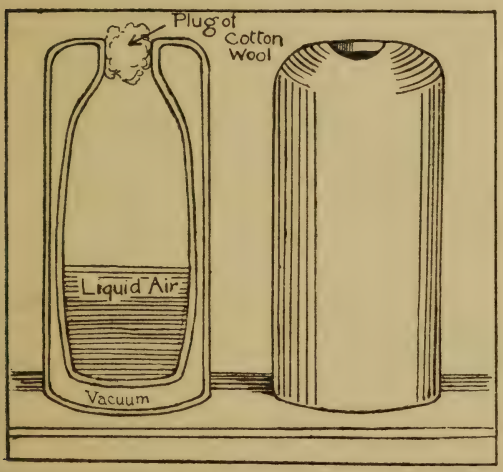

FIG. 26.—Vacuum Jacketed Vessel for holding Liquid Air. In these heat impervious flasks liquids may be kept hot or cold for days at a time.

The intense cold of this strange fluid may be illustrated by a number of remarkable experiments. Thus melting ice, cold as it seems to us, is actually 180° C. above the temperature of liquid air. It is consequently as hot in respect to it as fat frying in a saucepan is in respect to our bodies, or as molten lead is hot in respect to boiling water. If therefore liquid air be poured upon ice it will fly off hissing like water from red hot iron. If some liquid air be placed in a metal tea-kettle and then set upon a block of ice, the air at once begins to boil violently, and a white vapour as of steam

rushes from the spout and lid. If the kettle be placed over a fire of burning coals the heat of the fire causes the liquid to evaporate more rapidly and a stream of vapour shoots out of the spout to a great height. It looks like steam from a kettle of boiling water. If water be placed in the kettle as soon as the air has boiled away, it may be taken out as ice, while at the same time the bottom of the kettle will be found coated with solid carbonic acid and ice, frozen from the fire! And all this happens with the fire glowing only an inch or so below! It is very surprising, too, to see one's breath, blown into an open can of liquid air, sent back instantly with its moisture congealed into a miniature snowstorm. Even a jet of scalding steam is instantly frozen, for between steam and liquid air lies an abrupt temperature drop of nearly 300° C. Mercury is instantly frozen into a solid shining metal like silver! This solid metal is as hard as granite, and can be cast into swords and tools. Thus, if a little paste-board box be made in the shape of a hammer head and filled with mercury, and, after suspending in it a wooden rod to serve as a handle, if the whole be immersed in liquid air, in a few minutes the mercury will be frozen so solid as to form a veritable hammer which can be used for driving nails into hard wood!

Such experiments as these bring forcibly before the mind the abyss of cold which reigns in space about us. By contemplating the intense coldness of liquid air—itself a hot body in comparison to the cold of space—we are enabled to realise clearly how exceedingly hot the world's surface would appear to a being dwelling in the cold and darkness of the waste regions of the universe. Such a being landing on the surface of our planet would be shrivelled up like a piece of meat in an oven. If he managed to escape in time back to his cold gloomy abode, he would doubtless, like Mr. Wallace, sit down and write a book proving conclusively that no living beings could possibly exist on such a scorching world as the earth!

We must remember, too, that the earth's surface, like every other hot body, is radiating away heat and light into space, only our eyes are not sensitive to perceive it. In

FIG. 27.

FIG. 27.—Pouring liquid air out by the quart. When liquid air is thus poured out the intensely cold vapour causes all the moisture in the surrounding air to condense, and form billowy clouds, which roll along the floor in the manner shown in the illustration.

FIG. 28.—Kettle of liquid air boiling on a cake of ice. The ice is 180° hotter than the liquid air in the kettle, which is soon covered with frost.

FIG. 28.

Face page 146.

Le Bon's words :—" Down to the absolute zero of temperature all bodies incessantly radiate waves of light invisible to our eyes, but probably perceptible by the animals called nocturnal and capable of finding their way in the dark. To them, the body of a living being, whose temperature is about 37° C., ought to be surrounded by a luminous halo, which the want of sensitiveness of our eyes alone prevents our discerning. There do not exist in nature, in reality, any dark bodies, but only imperfect eyes. All bodies whatever are a constant source of visible or invisible radiations, which, whether of one kind or the other, are always radiations of light."*

Air is liquid at—180° C., and as we have seen, if we raise its temperature above this, it will boil just as water does when heated above 100° C. Steam, in fact, bears the same relation to water that ordinary air bears to liquid air. Since the earth's surface is nearly 200° C. above the temperature at which liquid air boils, it acts in the same way towards this fluid as a coal fire acts towards water. Hence we have only to expose liquid air to the heat of the furnace about us and in which we live, and it boils instantly, producing, like water surrounded by a fire, a vapour which expands and produces power. We can therefore use liquid air as a motive power.

The pressure exerted by liquid air in regaining its gaseous state is simply enormous. Hardly any closed vessel could withstand it. This becomes easily intelligible when we consider that a single cubic foot of liquid air contains condensed within it about 750 cubic feet of air at ordinary pressures and temperatures. If therefore it be left to absorb heat from the surrounding air it will expand by this amount, and, if prevented from so doing by being confined in a closed vessel, it will exert a pressure at ordinary temperature of over 10,000 lbs. (four and a half tons) on the square inch ! If heated the pressure would amount to from ten to thirty and more tons on the square inch. No ordinary boiler could resist such gigantic pressures. Yet one can realise easily that if this

* Le Bon, " The Evolution of Forces," p. 318 (1908).

force could be confined and controlled it would give rise to an immense amount of power. It has indeed been suggested that liquid air could be used for driving high-speed engines for flying machines and other purposes where great power combined with lightness is essential. The great obstacle to its use, however, is the freezing effect it produces. The moisture of the air is rapidly deposited as ice upon the machine, especially round the orifice from which the jet of extremely cold air emerges. This soon closes the exit-tube and stops the machine. There are other disadvantages too, which cannot be discussed here. The expansive power of liquid air may be demonstrated easily by pouring a little into a tightly plugged steel barrel. In a short time the plug will be expelled with a loud detonation, and sent whirling for hundreds of feet into the air. Some liquid air poured into stout steel or copper tubes which are then firmly sealed will in a short time cause them to explode like shells, sending the metallic fragments hurtling in all directions with great force.

Although liquid air is as harmless as water, and so long as it is not confined, cannot of itself explode, yet it is an extraordinary fact that, when mixed with other substances, it can form an explosive comparable in intensity to dynamite itself. Thus, in some experiments carried out by Mr. Trippler of New York, a bit of oily cotton waste, soaked in liquid air, was placed inside an iron tube open at both ends. This was laid inside a larger and stronger tube, also open at both ends. When the waste was ignited by a detonating fuse the explosion was so terrific that it not only blew the smaller tube to pieces, but it burst a great hole in the outer one as well.

Indeed in Germany practical use has been made of this fact in blasting in coal mines. Cotton wool impregnated with coal dust and steeped in liquid air is rammed into a hole drilled in the coal, and the whole exploded by a detonator in the ordinary way. The explosion which ensues is as effective as a dynamite one, but without its risks; for should a charge fail to explode in a few minutes all danger is past; because there remains only cotton and coaldust when the liquid air has evaporated. This is a valuable feature of its

use, since many lives are lost annually in attempting to remove dynamite charges which have for some reason or other failed to explode.

This property of liquid air is due to the fact that it contains oxygen in a very concentrated form. When it is mixed with a substance which will burn rapidly in oxygen, and a detonator is applied to the mixture, an explosively rapid combustion sets in, in which the sudden intense heat generated causes an instantaneous and violent rush of gas so that the whole goes off like so much dynamite. Indeed the actions in both cases are much the same, as we shall see when we come to deal with the latter body.

As we have already pointed out, air is composed of twenty-one parts of oxygen and seventy-nine parts of nitrogen. It begins to boil at −195° C., the boiling point of nitrogen. The nitrogen boils off first, leaving behind the oxygen, and so the temperature gradually rises until it reaches −183° C.

The more nitrogen it loses the bluer and at the same time the heavier the liquid becomes. This change may be shown easily by pouring a quantity of liquid air into a large glass bottle partially filled with water. For a moment it floats, boiling with great violence, liquid air being slightly lighter than water. When, however, the nitrogen has all boiled away, the liquid oxygen, being heavier than water, sinks in beautiful silvery bubbles, which boil violently until they disappear. A few drops of liquid air thrown into water will instantly freeze for themselves little boats of ice, which sail around merrily until the liquid air boils away. In this way ordinary liquid air exposed to the atmosphere becomes very rich in oxygen, and oxygen in such a concentrated form is a very wonderful substance. For instance, ordinary woollen felt can hardly be persuaded to burn even in a hot fire; but if it be dipped in this liquid oxygen, or even in liquid air, it will burn fiercely, with all the terrible violence of gun-cotton. A splinter of wood, when soaked in liquid air rich in oxygen, will burn like a fiery torch with immense power, while a glowing wood splinter plunged into liquid air bursts into furious flame, and

may cause the whole vessel containing the liquid air to be shattered by the heat developed.

Indeed, steel itself may be burnt by liquid air. To demonstrate this a tumbler of ice is made, and it is half filled with liquid oxygen. A burning match is then attached to a bit of steel spring and the whole dipped into the liquid air contained in the ice tumbler. The steel then burns, spluttering and giving out a glare of dazzling brilliancy. Between the liquid oxygen and the burning steel are about 2,000° C., and yet the ice tumbler is not affected. The oxygen is turned into a gas before combustion begins. For liquid oxygen itself probably will not support combustion. Instead of a steel spring, an electric-light carbon red-hot at its tip will burn in exactly the same way with dazzling brilliancy. Thus the abyss of cold which prevails in liquid air does not prevent it from acting as a powerful inflaming medium.

Liquid air introduces us to a strange cold world very different from the one in which we live. All things alter their properties to an astonishing extent at these low temperatures, and the exploration of the properties of matter under these new conditions is now steadily proceeding in all parts of the civilised world. Thus iron and steel increase their tensile strength immensely, but at the same time become as brittle as glass.

Seeds have been frozen in liquid air, and even in liquid hydrogen, and kept there for months at a time, and yet when thawed again they were found to be quite uninjured. On being planted they germinated and grew. In the same way the most intense cold will not kill many bacteria. Masses of deadly bacteria have been frozen for six months at a time in liquid air into dense solid masses ; yet when these bacteria are carefully thawed they become again active and living. Professor McKendrick froze for an hour at a temperature of −182° C., samples of meat, milk, etc., in sealed tubes. When these were opened after being kept at a blood heat for a few days, their contents were found to be quite putrid, showing that the bacteria in them had not been killed by the freezing process. Vital matter in this frozen state is neither dead nor

alive. It is in an intermediate state in which all vital activity is suspended. It will keep thus for thousands of years unchanged and immobile as a stone, and yet, when the right temperature is reached again, it will wake again to life and activity.

Of course this only applies to the simpler forms of life. Intense cold will always kill large animals. Thus, a man or a pig once frozen stiff into a hard brittle mass in liquid air, will never wake again, even if most carefully thawed. Still their flesh would keep quite fresh under such circumstances, and, indeed, frozen meat is imported in a quite fresh condition into England from all parts of the world. It is an interesting fact that in Siberia corpses of the mammoth, a kind of hairy elephant which has been extinct for ages, have been found buried in the ice, and in as fresh a condition as on the very day it sank to die ages ago upon the cold cheerless waste of ice and snow. Indeed, men and wolves have eaten the flesh of these preserved corpses without any ill effects afterwards.

These facts are of great intrinsic interest. Indeed, Arrhenius, the great Swedish chemist, maintains that by this means a mighty stream of life is kept circling in space from world to world about the whole of the immeasurable universe. He believes that tiny germs of life, tiny spores and bacteria, are borne to the upper regions of the atmosphere by winds and storms, and are thence driven out into the endless depths of space by radiation pressure from the sun. They rapidly under this influence attain a velocity of hundreds, nay thousands of miles a second and soon flash away into the utter darkness and cold of space. Here for countless ages they rush through immense waste spaces. No cold can kill them, nor time destroy them,* and so they wander for eternities of time chilled to an awful cold of nearly -273° C. ; but at last they flash into the upper atmosphere of some distant world. Usually such a planet is not in a suitable condition to receive them, being either too hot or too cold, and so the

* It has been suggested recently that the ultra-violet light from the sun would kill such life-germs when they reach the confines of the atmosphere.

germ perishes or lies dormant, perhaps for hundreds of thousands of years, until the climate alters and

" The hour comes to unfold it, and the need."

Sometimes it happens that they reach a planet in exactly the right condition to allow life to flourish. When this occurs we get gradually unfolding from this single germ a vast scheme of life, evolving into millions of different forms and passing in one long never-ending procession, ever from the simpler to the more complex,

" From earth to lichen, herb to flowering tree,
From cell to creeping worm, from man to what shall be."

Thus a formerly naked and desolate planet becomes covered with tiny microbes and great animals, plants, trees, birds and insects, spreading over all lands and seas, struggling upwards into the air and penetrating downwards into the dark depths of the oceans, and finally culminating in some intelligent animal which conquers to itself the whole planet, building great cities filled with marvels of art and science, and controlling all things with an iron hand.

In the course of time the conditions on this planet again become unfavourable to life ; and it slowly fades away again. Silence once more claims its own, and reigns throughout the once busy world. Our moon, perhaps, has gone through such a cycle of life, and is now a silent lifeless waste. Our own world, nay, all the worlds now rushing through space, thronged as many of them are with life, must all so perish in the course of time, an idea which Tennyson expressed in the beautiful lines:—

" Many a hearth upon our dark globe
Sighs after many a vanished face,
Many a planet by many a sun may roll
With the dust of a vanished race."

This steady remorseless oncoming of silence over the whole visible universe, and its ultimate burial in appalling darkness, has forcibly struck the imagination of more than one poet, a fact expressed by McArthur in his poem termed " Silence " :—

" Beyond the search of sun or wandering star,
In that deep cincture of eternal night
That shrouds and stays this orbèd flare of light
Silence is brooding, patient and afar,
Secure and steadfast in his primal right,
Reconquering slowly, with resistless might,
Dominions lost in immemorial war.
The throngèd suns are paling to their doom,
The constellations waver, and a breath,
Shall blur them all into eternity;
Then ancient silence in oblivious gloom
Shall reign—where holds this dream of Time and Death
Like some brief bubble in a shoreless sea."*

Although at the present time the air consists mainly of four volumes of nitrogen mixed with one volume of oxygen, yet the reader must not go away with the idea that the air always has had and always will have this composition; for all things are changing, slowly or quickly, and things which seem at rest are only apparently so. The air is no exception to this general law. It, too, is even at the present time changing its composition exceedingly slowly, so slowly that in the course of six thousand years no noticeable change has taken place. The Greeks and Romans must have breathed air of sensibly the same composition as that we now breathe; but the case is very different when we go back, not thousands, but millions and hundreds of millions of years. A slow continuous change going on for such vast ages can produce effects which astonish us by their magnitude. Suppose, for example, the amount of oxygen in the air diminished in a thousand years by only $\frac{1}{1000}$ per cent. This is a rate of change far too small to be detected by any measurement that we can make. Then in one million years the amount of oxygen would have diminished by one per cent. and in only twenty-one million years there would be no more oxygen left! Now the earth is, probably, well over a thousand millions of years old. In this vast interval of time it may have changed utterly and completely the composition of its atmosphere, not once, but many times. Indeed, we know for certain that ages ago the composition of the atmosphere differed

* *The Century Magazine*, Vol. 58 (1898-9), p. 706. Quoted by kind permission of Macmillan & Co.

entirely from its composition now. At that dim and mysterious period of the world's history when the whole surface of our planet was a white-hot sea of molten rock, the air consisted of steam, carbon dioxide, nitrogen, marsh gas, and perhaps hydrogen and helium. The free life-giving oxygen, which now maintains untold millions of animals in movement and vigour throughout the whole world, could not have been present at all in any considerable quantity.

The most astonishing thing about this early atmosphere was the enormous amount of that heavy choking gas, carbon dioxide, in it. The immense masses of this gas now stored up in the interior of the earth in chalk and limestone then floated free in the air, filling the valleys and hollows of the earth, and sweeping in currents all over its surface. This gas alone exceeded in volume the whole present atmosphere HUNDREDS of times. Hogböm and Chamberlin, as the result of careful calculation, show that the amount of carbon dioxide stored in chalk and dolomite must be between 400 and 600 times the present volume of the atmosphere ! These estimates are certainly far too low, because the pre-Cambrian limestones were not drawn into the calculation at all.

The pressures prevailing in this early atmosphere also awaken our astonishment. They probably exceeded fifteen tons on the square inch or over 18,000 tons on the square yard. Under such conditions, and in such an atmosphere, no man and no animal such as wanders to-day about the earth could exist even for a single minute.

These conditions did not last very long. As the earth cooled the steam gradually condensed to form the oceans and seas, while at the same time the carbon dioxide in it was gradually absorbed by the cooling rocks, until there now remains only a minute trace (0.03 per cent.) in the air we breathe.

We have many reasons for the statement that there was no oxygen, or at least very little, in the early atmosphere of the earth.*

* See Phipson, " Researches on the Present and Past History of the Earth's Atmosphere," London (1901). Also Arrhenius, " Das

In the first place, there were on the molten earth such enormous masses of substances which will combine with oxygen that the latter element must have been soon completely used up. For example, the amount of free carbon now deposited as coal and bituminous matter is enough to combine with nearly all the present amount of oxygen in the air—1,216 billion tons. Besides this there are large amounts of combustible iron pyrites, lower oxides of iron, etc., etc. Astronomical evidence confirms these conclusions. We know, for example, that free oxygen occurs in the sun's atmosphere, together with enormous excess of hydrogen gas. Now in all probability the earth's primeval atmosphere was of a similar constitution (since it too was once part of the same primeval fiery nebula from which our sun condensed), and contained hydrogen in excess.

As the whole system cooled the oxygen gradually united with the hydrogen to form water, leaving behind a great mass of free hydrogen floating about in the atmosphere. Perhaps also large volumes of hydrocarbon gases, such as marsh gas and ethane, were also present in this strange early atmosphere, since such gases are found in the comets which occasionally enter the solar system. Deadly cyanogen gas and vapour of prussic acid were also probably present in small amounts. In this weltering storm-shaken mass of gas the nitrogen now in the air we breathe was probably still present, and on account of its chemical inertness, has remained practically unchanged since the very earliest ages. Its antiquity, therefore, is enormous.

Phipson states that many of the higher plants, as well as many bacteria, will grow in an atmosphere consisting entirely of carbon dioxide and hydrogen. It is consequently possible that even in the earliest times there existed simple plants long before a noticeable amount of oxygen was present in the air.*

Indeed, the presence of oxygen in the atmosphere was

Werden der Welten," pp. 46-57 (1908), where the whole question is discussed critically in the light of recent researches.

* To some bacteria oxygen acts as a poison. Such organisms can only flourish in oxygen-free media.

probably brought about entirely by the vital activity of plant-life, which flourished on a vast scale in early ages, choking up the whole earth with the ruins of their decay. For, as we shall see in the chapter on carbon dioxide, green plants feed on the small quantities of this gas in the air, decomposing it under the influence of sunlight, retaining its carbon and setting free its oxygen. The carbon goes to build up the frame of the plant, and the oxygen escapes into the air. Arrhenius thinks that the earliest plants, living in an atmosphere of carbon dioxide, marsh gas, and hydrogen, but devoid of oxygen, gradually set free the combined oxygen in the manner described, and this, under the influence of electric discharges (for this strange primeval world heard, too, the roar of thunder and saw the flash of lightning), converted the free hydrogen present into water, and oxidised the hydrocarbon gases to carbon dioxide and water, until they were all used up. For untold æons of ages millions of plants, working silently but ceaselessly, steadily poured oxygen into the air until the present constitution was attained. No less than 1,216 billions of tons of oxygen were necessary to achieve this result, and the power to perform this gigantic task was all furnished by the gleaming sunlight of warm summers gone and forgotten ages before the foot of man, or the sound of human voice disturbed the silence of the primeval world! Botanists assert, however, that a certain amount of oxygen is absolutely necessary for the development of plant life. To meet this want Arrhenius supposes that when the world first condensed out of the solar nebula, it possessed, even in its outermost parts, an exceedingly high temperature. Under these conditions the lighter gases such as hydrogen and helium gradually flew off into space because the earth does not possess a gravitational attraction great enough to prevent particles moving with such great speeds as the molecules of these gases under the temperatures then prevailing from flying off into space. On the other hand, there remained behind the heavier gases such as nitrogen and oxygen, their molecular velocity being much less. The original excess of hydrogen and helium, therefore, vanished before the solid crust of the earth was formed, so

that in the earth's atmosphere, immediately after the formation of the crust, there was present a certain amount of oxygen, together with much nitrogen, carbon dioxide, and steam. Nevertheless this does not affect the general conclusion arrived at above that the greater part of the oxygen in the air was, as Phipson suggested (and before him, Koehne in Brussels in 1856), set free by plants decomposing the carbon dioxide.

However this may be it seems certain that the presence of oxygen gas is an essential condition for the coming into existence of animal life. Animals are, so to speak, parasites which live on plants and absolutely depend upon them for nourishment. Plants, on the other hand, need, besides a suitable temperature, only carbon dioxide and water, and these gases occur in the atmosphere of probably every planet, being thrown out as waste products from the cooling masses of their inner glowing interior.

Thus we see that the atmosphere is no inert changeless mass of gas ; it is changing now even as we live and breathe in it, and it has never ceased to change since that far-off time when it whirled as a fire mist through space. As it is at present constituted it is the product of long ages of steady evolution. The passing wind can relate a story of its long journey down the stream of time more wonderful than any fairy tale.

The ultimate fate of the atmosphere is a melancholy one to contemplate. It will ultimately vanish altogether from off the earth's surface.* There are at least two influences which, acting singly or conjointly, will infallibly bring about this result. The first of these influences is the cooling of the earth's exterior in consequence of a diminution of the sun's radiating power. As already mentioned, the atmosphere is merely that portion of the original nebula from which the world was formed, which has not yet condensed to a solid or liquid form owing to the fact that the temperature of the earth's surface (being nearly 300° C. above the temperature of surrounding space) is still sufficiently high to maintain

* It is uncertain to what extent the presence of heat-evolving radium in the sun and earth will affect this conclusion.

it in a gaseous state; but the temperature of the earth's surface is mainly dependent upon the amount of heat radiated from the sun. Since the sun itself is a cooling body, its heat and light-giving properties must in the course of time gradually diminish in strength until they die away altogether. Then our luminary will relapse into a state of death and the whole solar system will be plunged in utter darkness and cold. Hence, as the sun's power diminishes, the world will become colder and colder. First, a mighty frost will grip the whole world and turn all its waters into ice. Then the air will condense, first to a liquid and finally to a solid state. This will happen when the temperature of the earth's surface falls below—180° C. This temperature is not so enormously remote as is generally imagined from those prevailing in the coldest regions of the earth. For example, a temperature of—61·7° C. has been recently (1905) recorded in Bothia (Canada) by Captain Amundsen; and it might well happen that a temperature of—90° C. occasionally prevails at the Pole itself. We have now only to imagine an equally great additional lowering of temperature in order to cause the air itself to liquefy! As the world continues to cool there will surely come a time when the air will begin to condense in the upper regions of the atmosphere to vast white clouds composed of droplets of liquid air. These sinking downwards will cause the air to be gradually deposited in the form of immense shallow seas of light blue colour—seas so intensely cold as to burn us like molten lead! These seas will roll over the places where the oceans of to-day lie; but of course the water of the latter will long since have been transformed into hard masses of ice, presenting much the same appearance as marble or quartz, and regarded by the shivering inhabitants (if any exist) of this land of dreadful cold as a rock.

All the aqueous conditions of to-day will be exactly paralleled by this liquid air. For example, just as we now have rain composed of water drops, so then at a temperature of—190° C. we shall have showers of liquid air! The earth will be tipped with white poles of frozen air, forming great ice-masses much like our present polar ice-caps, while ice-

bergs of solid air will float south in its seas of liquid air !

Last of all, when the temperature falls below—210° C., the air will freeze to a solid layer of an ice-like transparent mass about thirty-five feet thick. No gaseous atmosphere will then exist upon the earth. This will become an intensively cold dark wilderness. Then, after untold ages of ceaseless movement and gigantic change, the surface of our planet will at last rest in supreme repose, motionless and utterly silent. For, in the absence of a gaseous envelope, no moan of wind or roll of thunder, no splash of rain, no roar of torrent, no sound of voice of man or beast or bird, can pierce the blackness of the night and break its everlasting calm. The surface of the world will be a vacuum as perfect as that prevailing in Dewar's vacuum-jacketed flasks. The stars will shine out of a coalblack sky upon a lifeless world, set stiff and hard in the rigid grip of death, circulating unseen and ghostlike in the darkness around a burnt-out sun. Yet, only a few miles down in its interior, in strange contrast to the dreadful death-bringing cold of its surface, the gigantic furnaces of the deep, immense reservoirs of power and energy, will still gleam and glow. So the world will continue for long æons of ages, until its matter dissolves away and rushes into the oblivion of the ether, or until it is shattered in some mighty cosmical collision and resolved into a glowing nebula again, only to begin anew another vast cycle of life.

Even if the sun maintains its present power of radiation indefinitely this will not prevent the ultimate loss of the earth's atmosphere ; for it is the intense internal heat of the earth which keeps a layer of gas around its surface. Only a few miles down the white-hot glowing furnaces effectively expel any air or water reaching to such depths. When the interior of the earth cools sufficiently (as it must ultimately) the whole atmosphere together with the waters will retreat into it much in the same way that ammonia gas condenses into charcoal or water soaks into blotting paper.

Thus, as the great world spins through its scheme of everlasting change, the atmosphere which clothes it round also undergoes a series of wonderful and mighty transformations,

fraught with the greatest consequence to all things that live and move on land and sea. The atmosphere, like all other things of nature, has had a wonderful past and will yet have a wonderful future.

It has been estimated that in the heavens shine more than a hundred million suns. Many are known, from spectroscopic evidence, to possess systems of planets whirling round them. Doubtless all possess one or more such planets. There may, therefore, exist hundreds of millions of planets, in many respects similar to our earth, scattered through our sidereal system. It thus becomes very interesting to inquire into the constitution of their atmospheres.

The first question one naturally asks is, Have they all atmospheres like our earth's? The answer to this is that these worlds have atmospheres of almost every conceivable constitution. On some of them substances which are the most abundant constituents of our atmosphere are entirely wanting; while on the other hand substances existing here in our atmosphere in the minutest traces may there be present in the greatest abundance. Many of the planets possess no atmosphere at all. As we have just seen, one of the essential conditions for the possession of an atmosphere is a red-hot or white-hot interior—in other words, a degree of internal heat sufficient to drive out all gases from the interior and maintain them on the surface of the planet.

It can be demonstrated that there is a critical velocity for every globe, such that if a body be projected upwards with that critical velocity or any greater one, it will escape altogether. Take, for instance, the case of the earth. It can be shown that for any globe possessing the exact size and weight of the earth, the velocity with which a missile would have to be shot upwards so as to effect its escape must be about seven miles a second. If the velocity with which the body started on its vertical ascent were less than seven miles a second, then, after reaching a height dependent upon the speed of projection, it will commence to return. If, however, the speed be more than the critical value of seven miles a second, the body will continue its journey, and the attraction of the earth will not be sufficient to recall it. Now

all the gases which, at some time or other, coat the surfaces of planets, must be regarded as composed of a number of rapidly flying projectiles, viz., the molecules. If the gravitational force of the planet is not powerful enough to restrain them, the rapidly moving molecules will gradually dart away into space and be permanently lost to the atmosphere. Only a planet of a certain size, therefore, can retain a gaseous atmosphere, a fact, indeed, which is in agreement with astronomical observation.

Dr. Johnstone Stoney has calculated the mass needed to secure to a planet the lasting possession of an atmosphere. It differs for the different gases; for the particles of the lighter gases travel the more rapidly than those of the heavier gases and thus require a greater planetary mass to retain them. For example, the earth cannot permanently retain hydrogen because a definite percentage of hydrogen molecules at ordinary temperatures travel with a velocity greater than seven miles a second, the critical velocity of the earth, and so they slowly escape into space, until in the course of ages practically all the hydrogen has vanished. On the other hand the earth is capable of permanently retaining the other constituents of its atmosphere, such as oxygen, nitrogen, argon, and carbon dioxide.

The conditions reigning on the moon are very different. Here the gravitational attraction is only one-sixth that of the earth, and consequently a gaseous molecule possessing a velocity of only 1.25 miles a second will fly away from it into space. Now the highest temperature of the moon's surface (the centre of the full moon) is about 150° C. At this temperature the velocity of the hydrogen molecule is 1.45 miles a second, that is to say, greater than the critical speed. Therefore hydrogen must disappear from this part of the moon in a steady stream into space, and since hydrogen diffuses to this point so long as there is any gas remaining, the hydrogen, if it once existed in the atmosphere of our satellite, must have very soon disappeared from it. Similar reasoning holds for oxygen and nitrogen, and, in a slightly less degree, for argon as well. It is therefore no wonder that we find no trace of an atmosphere on the moon. In its

deeper valleys, and underground caverns, however, there may still lurk some dense gases like carbon dioxide; yet for the most part the surface of the moon is in a vacuum as perfect as can be produced by our best air pumps. Its bare rocky surface is covered with vast craters, surrounded by mighty walls of slag and lava jutting up into the vacuum to a height of 11,000 or 12,000 feet. Aqueous vapour plays a great part in our own atmosphere. On the moon, however, no traces of it are met with; consequently no mists or clouds cling to its valleys and mountain tops, and no rivers or seas fill up its low-lying parts. Some recent writers, however, have maintained that much of the moon's surface is incased in snow and ice. From certain huge ring-craters, such as Tycho and Copernicus, snow-white streams or rays diverge, which, it has been suggested, are ancient glacier streams. The whiteness of the great mountain Aristarchus has been similarly explained. The flashing back by this peak, of earthshine at determinate angles of illumination, has often counterfeited the vivid glow of actual eruptions. However this may be, there can be no doubt that now, since there is no erosion of air or water, repose reigns undisturbed over all its surface.

Venus, being about the same size as the earth, retains the same gases. It possesses a lofty and dense atmosphere which has been estimated to weigh twice as much as ours. Water vapour has been definitely detected in its atmosphere. Indeed the planet is wrapped round by vast steam clouds which hide its surface from us and prevent us from seeing the rivers, continents, and oceans, which doubtless extend far and wide underneath them.*

Arrhenius comes to the conclusion that its average temperature is about 40° C., and that it is well fitted for life such as prevails upon this earth. It may be thronged with living forms, with great cities, and intelligent beings, yet so long as its vast canopy of cloud covers its surface no human eye

* Recent observations indicate that one face of Venus is permanently turned sunwards and is warm, while the other side, away from the sun, is dark and cold. If so, terrific winds must rush from the hot side to the cold, while most of its waters must have distilled away from the sunlit face and condensed as ice on the cold face.

can ever hope to obtain an indication of their presence. Mars is a small planet possessing only one-ninth of the mass of the earth. Its gravitational attraction is somewhat over one-third of that of the earth, just sufficient to allow it to retain oxygen, nitrogen, water vapour, and carbon dioxide. On account of its small mass it possesses a thin but extensive atmosphere, of a density about one-seventh that of ours. It is more than twice as tenuous as the air at the summit of the Himalayas, yet clouds form and mists rise in this thin Martian air. During the latter half of October, 1894, an area much larger than Europe remained covered with rain clouds. In the pure sky the sun shines gloriously, exhibiting its coronal streamers and prominences as part of his noontide splendour. Atmospheric circulation proceeds so tranquilly as not to disturb the repose of a warm land basking in a bright sunshine. Water certainly exists in this atmosphere. It has been detected by means of the spectroscope; while we can actually see its snowy poles, seas, and great engineering works which look like canals, and which Lowell believes to be the work of intelligent beings. Vegetation, too, probably flourishes on this little globe because the colour of the plains and canals alters with the season of the year. Quite recently oxygen is stated to have been discovered as a constituent of its atmosphere.

The planet Mercury is small compared with the earth, and consequently possesses hardly any atmosphere. Its critical velocity is three miles a second, compared with the earth's seven. It may therefore contain a very small amount of water vapour and the very thinnest of aerial coverings.

The giant planets Jupiter, Saturn, Uranus, and Neptune, seem all to be so hot as to exist in a gaseous or liquid condition. Their surfaces are hidden from view by vast clouds of condensed steam. These planets are heavy enough to retain the lightest gases in their atmospheres. Their upper regions may, therefore, consist of hydrogen, helium, nitrogen, carbon dioxide, sulphur dioxide, besides, of course, steam. Their lower regions are probably white hot and may contain gaseous metals such as iron and calcium. The spectroscope shows that mysterious elements occur in the atmospheres of

these planets which are quite unknown upon this earth. Thus an intense red band occurs in the spectrum of both Jupiter and Saturn, of wave length 0.000,618 mm., which corresponds to no known earthly element. Other new and unknown substances gleam forth in the light that Uranus and Neptune send us.

The sun, with a mass nearly 332,000 times that of the earth, is heavy enough to control the molecules of the lightest gases. Before they can escape their molecules must fly with the speed of 391 miles a second. Very few gaseous molecules attain such great velocities as these and consequently the sun's atmosphere is enormous. Its upper regions consist of vast quantities of the lighter gases hydrogen and helium, as well as a gas still unknown upon the earth, the mysterious Coronium, which flares forth a vivid green light far above the hydrogen layer. The sun's lower regions consist of gaseous iron, calcium, magnesium, and other metals, for the temperature of the sun is so immensely high that such metals boil and vaporise on its surface much as liquid air boils and vaporises on our earth.

We have no knowledge regarding the constitution of the atmospheres covering the countless millions of invisible worlds of space, worlds that we can never hope to see or directly investigate.

Doubtless some possess atmospheres very similar to those surrounding our own earth. Others, however, must possess gaseous envelopes quite different from those which clothe the planets of the solar system. The mysteries which lie hidden on these strange and distant worlds are probably more wonderful than anything that we can even imagine.

CHAPTER VIII

OXYGEN, THE LIFE-SUPPORTING ELEMENT

FEW of the grand truths of science have so forcibly impressed themselves upon the imagination of man as the fact that every speck of living matter in this wide world of ours is ceaselessly burning away. A burning coal or candle vanishes ultimately into the invisible gases carbon dioxide and water vapour. By an exactly similar, but slower process of combustion, every man and every woman upon this earth, every living creature that walks or flies or swims, is passing away moment by moment into the same invisible products of combustion. It is indeed the heat generated by this slow continuous combustion that keeps our bodies warm and leads men to compare life to a slow-burning fire.

The agent which causes and propagates this combustion is the oxygen of the air. Upon the presence of this colourless invisible gas hangs the whole vast fabric of animal and, perhaps, of vegetable life as well. Each breath we draw represents the inward rush into our bodies of millions upon millions of tiny oxygen atoms, which at once begin silently and swiftly to clash against molecules of living matter in the blood, and to combine with them, and, so to speak, burn them up. Each outward breath also represents a similar swift outward rush of myriads of molecular systems—the smoke and waste gases from the furnace of our bodies. This, one of the most remarkable and mysterious facts of life, was long ago beautifully expressed by Holmes in the stately lines :

> " God has made
> This world a strue of atoms and of spheres.
> With every breath I sigh myself away
> And take my tribute from the wandering wind,
> To fan the flame of Life's consuming Fire."

The most wonderful thing about it all is that although we are thus wasting away rapidly into invisible gases, yet all the time our individuality remains unchanged. The whole matter of our bodies may be, perhaps in five years, burnt up and replaced completely atom by atom by fresh matter, and yet we remain the same being. Within a few months by far the greater part of the carbon of our bodies has been evolved as carbon dioxide, and its place taken by fresh carbon particles derived from the food we eat, yet we still remember the events of years ago, when our bodies were composed of an entirely different set of atoms. Though the matter forming our bodies is changing ceaselessly, life, the sum of its changes, does not appreciably alter from year to year. And this, in brief, is the epitome of all life, not only of that of the individual, but of that of the race as well :—

> " Still glides the stream, and shall for ever glide,
> The form remains the function never dies,
> While we, the brave, the mighty, and the wise,
> . . . . must vanish. Be it so !
> Enough if something from our hands hath power
> To live and act and serve the future hour ;
> And if, as toward the silent tomb we go,
> Through love, through hope, and faith's transcendent dower,
> We feel that we are greater than we know."

In the human body this process of slow oxidation or combustion is carried out by a very wonderful piece of mechanism, which we will now proceed to describe. Air containing one-fifth of its bulk of oxygen is sucked into the lungs and is there brought into contact with the blood. The oxygen in the air then combines with the blood and endows it with its rich red colour—hence the rosy hue of health. The nitrogen, however, is breathed out unchanged, accompanied by the products of combustion.

When the blood loses oxygen it takes a bluish tint seen in the veins. The blood, therefore, is the oxygen carrier of the body ; and it is the red corpuscles in it which absorb oxygen because they contain a substance called hæmoglobin, which forms a chemical compound with this gas and carries it through every part of the body, thus :

Hæmoglobin + Oxygen = Oxy-hæmoglobin.

This oxy-hæmoglobin holds its oxygen only very feebly and readily yields it to substances in the blood which need it :

Oxy-hæmoglobin = Hæmoglobin + Oxygen.

This oxidised blood, driven through the arteries by the heart, commingles with the living cells, the minute masses of living matter, myriads of which form each organ ; the blood trickles between the cells through channels as fine and as close-set as the pores in unglazed porcelain. The living cells in each organ take from the blood the oxygen that they require. It is in the cells themselves that the oxidation of the food stuffs takes place, and the end result of this oxidation or combustion is that the carbon (the black element contained in coal and charcoal, which appears when animal or vegetable matter is charred) is evolved in the form of the invisible gas, carbon dioxide, thus :

$$\underset{\text{Carbon}}{C} + \underset{\text{Oxygen}}{O_2} = \underset{\text{Carbon Dioxide.}}{CO_2}$$

Hence this gas is evolved in the expired air, and, as already stated, the warmth of the body arises in part as the result of its slow production, which goes on not only in the lungs but more or less throughout all the tissues of the body. We breathe to a certain extent through the skin itself. What an interesting substance is this hæmoglobin ! The physiologists can extract it from the blood, and you can see it on their microscopic slides as a mass of beautiful reddish crystals, some of which are shown in the illustration (Fig. 29). When it combines loosely with oxygen it assumes a bright scarlet

Fig. 29.—Crystals of Oxy-hæmoglobin—prismatic, from human blood. (Illustration from Haliburton's *Physiology*, published by Mr. John Murray.)

colour. When the oxygen is removed by treating it with substances which take it up the crystals assume the bluish tint of Hæmoglobin.

Hæmoglobin combines not only with oxygen but also with other gases such as carbon monoxide and nitric oxide, and it is this fact which makes these substances such deadly blood-poisons, as we shall see later.

This wonderful crystalline substance contains carbon, sulphur, oxygen, hydrogen, nitrogen, and about 0.4 per cent. of iron. One gram of hæmoglobin will combine with 1.34 c.c. of oxygen. Yet so feebly does it hold this additional oxygen that it will stream out of it and escape when the substance is placed in a vacuum. The whole of our vital processes depend upon this curious compound, and its colour gives blood its splendid crimson tint.

In some other animals, however, it is replaced by other respiratory pigments. Thus a green one, chlorocruorin, is found in certain worms, and a blue one, hæmocyanin, is found in many molluscs and crustacea. The first contains iron and the second copper. Think of green or blue blood! The idea seems curious. If we had these respiratory pigments in our blood instead of hæmoglobin, this fluid would have been of a magnificent green or blue colour! On other worlds beings may exist having the most astonishing contrivances for absorbing gases from their atmospheres and thus rendering the continuous combustion of their bodies possible. Indeed a minute study of the wonders of animal and vegetable life upon our earth prepares us for undreamt of and hardly imaginable devices in other forms of life which have developed along altogether different lines on other planets. Such secrets, however, will probably remain for ever hidden from human scrutiny.

Thus we see that so far as the animal world is concerned oxygen is the chemical centre of Nature. "Without sufficient oxygen," says Dr. Leonard Hill, "the power of the Prime Minister to control the Empire fails no less than that of the sweeper to sweep his crossing." It is indeed the source of every man's power. Remove it from the air and destruction swift and terrible would fall upon living matter

as surely as night follows day ; for although a man may do without food or drink for days at a time he cannot do without that food of foods, oxygen, for more than a few seconds. Consequently within five minutes of its withdrawal from the vast ocean of gas in which we live the world would be converted into a vast charnel house ; yet by such an operation the surface of the earth would not be apparently changed to a being looking down upon it from another planet ; the sun would still shine through a smiling blue sky, and the waters would still ripple and surge as of old, but the invisible vitalising principle would be irretrievably gone from the air.

Within sixty seconds of the withdrawal of oxygen animals would roll in convulsions, rapidly suffocating, and within five minutes the whole world would be hushed in death. It is true that trees and plants would continue to flourish for some days, but they too, according to botanists, need some oxygen and would also ultimately perish. The seas would become covered with the dead bodies of millions upon millions of fishes, suffocated by the failure of oxygen dissolved in water, by means of which they breathe. The only beings that would continue to flourish in this oxygen-free atmosphere would be a few minute bacteria. Indeed from them in time a race of beings might evolve which would re-people the world anew with organisms capable of flourishing under the new conditions.

Thus our very existence hangs like a thread upon the supply of oxygen that we receive minute by minute from the air. Yet, so smoothly runs the course of our lives, few of us think of this in daily life until it is forcibly brought to our notice by some tragic episode, such as a great pit explosion, like that at Courrières in 1906, whereby hundreds of lives were suddenly annihilated in the dark depths of the mine, not by fire or flame, but by the sudden using up of the oxygen in the air they breathed as the result of the explosion.

We must now say a few words about the appearance and properties of the element which produces all these wonderful results. Oxygen gas looks exactly like ordinary air, and except for the fact that it is slightly heavier, there is nothing in their physical properties to distinguish between them. In

large masses it is blue, and indeed the blue colour of the sky has been held by some authorities to be due to the presence of oxygen. Yet how strangely different are its chemical properties from those of ordinary air! Things which burn but feebly in the ordinary air blaze forth with the utmost fierceness when plunged into the pure element itself, emitting a dazzling light and generating an intense heat. Many things which will not burn in air at all are combustible in oxygen. For example, if we take a piece of steel watchspring and, after fastening a little sulphur to the end of it and lighting it, plunge the whole into a jar of oxygen, the steel instantly begins to burn, spluttering and throwing out a stream of brilliant sparks. The following change takes place:

$$\underset{\text{Iron}}{3Fe} + \underset{\text{Oxygen}}{2O_2} = \underset{\text{Magnetic Iron Oxide.}}{Fe_3O_4}$$

The pale blue feeble flame of sulphur burning in air is transformed in oxygen into a magnificent lilac-coloured flame. A gas known as sulphur dioxide is produced, thus:

$$\underset{\text{Sulphur}}{S} + \underset{\text{Oxygen}}{O2} = \underset{\text{Sulphur Dioxide.}}{SO_2}$$

Those of you who have only seen a candle burn in the diluted oxygen of our air can hardly form an idea of the brilliancy and glory of its flame in pure oxygen, the carbon in it burning to carbon dioxide and the hydrogen to water vapour.

Now it is a mere accident that our atmosphere contains only twenty per cent. of oxygen. This oxygen was gradually set free by millions of plants working ceaselessly for untold ages, and had not the vegetative processes been greatly diminished from time to time by periods of arctic cold, it may well have happened that at the present day the percentage of oxygen in the air had risen to over ninety per cent. We should thus have been living in an atmosphere of practically pure oxygen. What a vast difference this would have made to our lives! All our domestic arrangements would certainly have had to be ordered otherwise. Think, for example, of the fact that it would be quite dangerous to burn either coal or wood or to use iron grates.

For these substances would burn so furiously, emitting such a dazzling light, and generating such intense heat, that they would be all consumed in a few minutes.

To maintain a coal fire under such conditions would be something like maintaining a fire of cotton wool or paper under ordinary conditions. Moreover, so tremendous would be the heat that the very iron grates which confined the coal would melt, catch fire, and burn away like an inflammable substance. So that iron boilers, grates, stoves, and heating machinery generally would become almost an impossibility on this oxygen planet. A house on fire would be altogether a terrible affair, for it would blaze up in a few moments and shine with the brilliancy of an arc lamp, while molten iron streams would come flowing out of the house burning as they rolled. I suppose no fire engine in the world could put out such a conflagration.

Tobacco-smoking would certainly have been an unknown habit; for in this fiery atmosphere tobacco would catch fire like paper, and disappear in a whiff of furious flame! All this seems very strange, and yet there probably exists many a planet where these conditions are fulfilled, and whose atmosphere consists almost wholly of pure oxygen gas. If in addition the atmospheric pressure of such an oxygen planet were much greater than that of our earth, not only would these effects be greatly exaggerated, but coal and wood under these circumstances would burn so furiously as to produce an explosion! A knowledge of the facts of science shows us that the possibilities lurking within this vast universe of ours are so strange as to surpass in weirdness any fairy tale.

When oxygen gas is cooled to a very low temperature (—183° C.) it condenses to a beautiful blue liquid whose properties were discussed in our chapter on liquid air. One strange thing about this liquid is that it is strongly magnetic. This may be shown by placing a little liquid oxygen in a glass between the north and south poles of a powerful electro-magnet, when the fluid is seen to be attracted by the poles, heaping up over each to an appreciable extent. Here, all unsuspectingly, the

chemist obtains a glimpse of the vast complexity and titanic forces which prevail in the world beneath the atom; for the mere fact that oxygen exhibits magnetism shows that its atoms not only have whirling round them with tremendous velocities large numbers of negatively charged electrons, but that, in the magnetised oxygen at least, these orbits all lie in the same plane, like those of the planets in the solar system.* The molecules of oxygen, like those of hydrogen, consist of two circling atoms, which fly at 0° C. with the speed of 461 metres a second. The diameter of the molecule has been estimated at about 2×10^{-8} cms. That is to say, 200 millions placed in a row would just cover the breadth of your little finger nail! and yet objects so tiny are themselves great universes, each atom being, according to Sir Oliver Lodge, made up of about 30,000 separate electrons! At ordinary temperatures and pressures there exist within each cubic millimetre of oxygen gas, that is to say, within the volume of a large-sized pinhead, no less than 42,090,000,000,000,000 molecules. So that oxygen gas is, like all the other things of Nature, a very complex thing indeed.

The use of oxygen as a means of allowing men to enter into poisonous atmospheres, such as exist in exploded coal mines, in stagnant sewers, gasometers, cellars, and underground places, has lately been brought prominently to public notice. In the majority of modern oxygen breathing apparatus the oxygen is compressed in strong steel cylinders often to 100 or 120 atmospheres, and is allowed to stream slowly out into an indiarubber bag or reservoir, and is thence directly breathed through tubes which fit into the mouth. The carbon dioxide gas breathed out from the lungs is absorbed by means of caustic soda placed in the rubber breathing-bag in front. By means of this continual supply of fresh oxygen men can advance and work for hours in poisonous atmospheres. The illustration (Figs. 30, 31) shows the Fleuss-Siebe-Gorman breathing apparatus, which is one of the best of this type. Several other excellent oxygen breathing apparatus exist, such as the Draeger, but we cannot discuss them here more fully.

* See Fournier d'Albe, "The Electron Theory," p. 159 (1906).

Current literature abounds in cases where oxygen supplied in this manner has enabled life and property to be saved. One of the earliest cases on record occurred at the Killingsworth Colliery in 1882. Eight miners were imprisoned by the collapse of a shaft, and the Fleuss apparatus (an older form of that just described) was employed in getting them out.

Quite recently another case occurred at the Elswick Works of Sir W. G. Armstrong, Whitworth and Company.* It appears that a workman entered an old tunnel shaft of a furnace with the object of repairing it. But the shaft was full of poisonous gas, and to the horror of the men above the man fell unconscious. Luckily an oxygen-breathing apparatus was at hand, and the poor fellow was, by its means, soon pulled out into safety, and was resuscitated by means of artificial respiration.

At a terrible colliery disaster at Reden, in Prussia, a rescue party armed with this apparatus saved no less than twenty-six lives, while in a similar disaster at Merlach eight lives were saved.†

In this work, however, the rescuers themselves run a considerable risk. Thus at the fearful Courrières disaster in 1906, where a terrible explosion shattered the great mine and filled the workings with poisonous gas, no less than 1,100 men perished, principally by suffocation. A rescue party breathing oxygen advanced into the black shattered depths to search for men still living. When in the midst of the frightfully poisonous atmosphere the oxygen of one of the rescue party began to fail, and in desperation he tore off his helmet, probably scarcely realising the danger of so doing. The unfortunate man immediately fell unconscious, and before the body could be brought out life was extinct.

Recently another rescuer lost his life in the sad Hamstead disaster, near Birmingham, in March, 1908. This case is of interest because it shows what rescue apparatus can do in enabling men to penetrate places in which no living being could otherwise exist for a single minute, and we will therefore give a fuller account of it. A candle left carelessly

* *Trans. Inst. Mining Engineers*, 1907, Vol. 35, p. 224.
† *Ibid.*, Vol. 37, p. 83.

about caused the woodwork at the foot of the main shaft to catch fire. Immediately there was a great conflagration, and a few miners dashing through the flames managed to reach the cage and were hauled safely to the surface. The others, to the number of twenty-five, found their retreat cut off by a wall of advancing fire and fled into the depths of the mine, where they were suffocated by the poisonous fumes evolved from the burning coal. Above the shaft the greatest excitement prevailed, and rescue parties armed with oxygen-breathing apparatus descended into the burning mine. The conditions of work were terrible. The workings of the mine where plunged in absolute darkness, and the dense smoke from the burning coal and woodwork scarcely allowed the rescuers even with their electrical lamps to see more than a yard or so in advance. They bravely groped their way onwards until they had penetrated nearly half a mile into the workings, but here they were stopped by a terrible heat and smoke. As time wore on the fire spread, and a large part of the mine became a fiery furnace. An illustration in the *Graphic*, March 14, 1908, shows a party of the rescuers armed with the Draeger oxygen-breathing apparatus groping their way forwards into the burning depths. Several desperate attempts were made to advance, and it was in one of these that the rescuer Welsby lost his life. He fell unconscious while working nearly half-a-mile from the foot of the shaft. Whether it was that his oxygen gave out or whether the terrible heat in the confined space in which he worked occasioned a fainting fit will now probably never be clearly established. He was working in company with a man named Whittington, and the latter carried and dragged his mate for some distance at the imminent risk of his own life until his supply of oxygen had also nearly spent itself, and he was forced to struggle back to the cage. He, too, would have fallen a victim had he not been found by a comrade. All subsequent efforts to reach the heroic Welsby proved unavailing. After hundreds of tons of water had been poured into the mine another attempt was made to enter it, but by this time the fire had spread so terribly that it was now impossible to reach even

the bottom of the shaft. Now although in this case no lives were actually saved, and one was actually lost, yet we have a demonstration of the fact that men could travel and work for hours in a burning mine every part of whose interior was filled with frightfully poisonous gas, so poisonous, indeed, that a few mouthfuls would have probably been fatal.

A great many collieries are now provided with these apparatus, and by their prompt action fires in mines can be stopped. Once a small fire begins in a mine the air becomes so bad that men cannot approach it to put it out and so it gradually grows into a vast conflagration; but provided with these oxygen-breathing apparatus the men can advance promptly and dam up the workings and then extinguish the fire by pouring water on the blazing coal.

Perhaps the most sensational use ever made of an oxygen-breathing apparatus was that made by Mr. Fleuss when he saved the Severn Tunnel from flooding in 1880.* It appears that while the men were tunnelling deep under the Severn, a flood of water suddenly burst into the tunnel from some subterranean spring. Panic seized the workmen, and they fled with the water roaring after them, and only narrowly escaped with their lives. Now, in order to provide for such a sudden disaster, an iron door had been constructed by the engineers, which could hermetically close the passage, and so prevent the water from progressing further. The men, thinking that the whole Severn river was pouring in upon them from the fractured wall, fled without closing this door. The consequence was that in a few hours the workings had been drowned completely, the water standing 150 feet deep in the shafts. Great pumping engines were erected and ultimately the level of the water was reduced to thirty-nine feet in the shaft. Further it was impossible to go.

The only hope of success lay in closing the iron door, and so stopping the inward rush of water. To do this a diver had to descend into thirty-nine feet of water, and then creep along a passage all under water and in absolute darkness

* See *Trans. S. Wales Mining Institute*, 1880, Vol. 12, p. 100, and pp. 350, 351. A popular account is given in "Engineering Wonders of the World," Part II., pp. 83, 84. (Nelson & Son).

for the fifth part of a mile before he reached the door at all. Moreover, the way was jammed up with two trams, over which it was necessary to crawl in the dark, and remove some metal rails which had caught in the door and prevented it from shutting. The diver Lambert first started on his

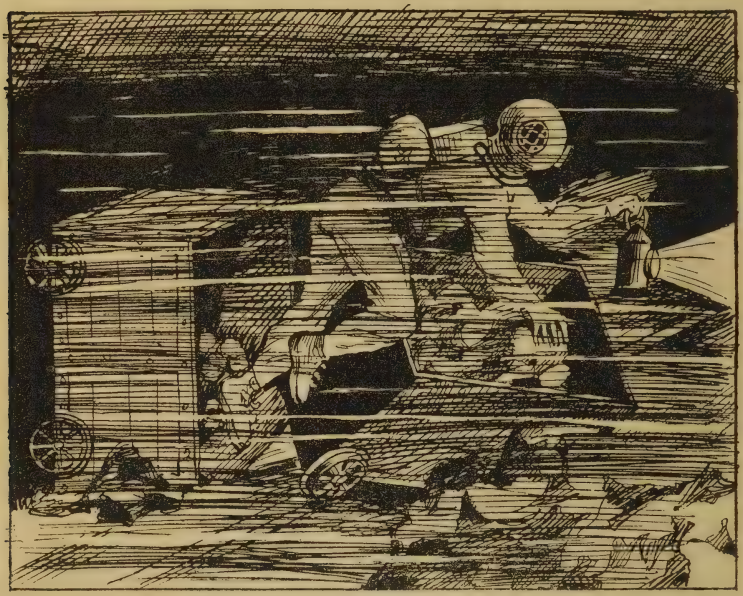

FIG. 30.—How the Severn Tunnel was Saved from Flooding in 1880 by the use of compressed oxygen attached to a diving suit. A sudden inrush of water having flooded the workings it became necessary to send down a diver to close a certain water-tight door which would stop the inrush of water. Ordinary diving suits were inapplicable on account of the weight of the air-tubes. The, at that time, recently-invented Fleuss Oxygen-breathing Diving Apparatus, which was an ordinary diving suit carrying a supply of compressed oxygen on the back, enabled the diver Lambert to walk over 1,020 feet along the drowned passage, climb over two overturned waggons which blocked the road, and close the door.

perilous journey in an ordinary diving suit, and, armed only with a short iron bar, groped his way carefully yard by yard in total darkness over the debris which strewed the floor, past overturned waggons, lumps of rocks, and tools which had been cast away by the workmen as they fled. He actually

FIG. 31.—The Oxygen Breathing Apparatus (Fleuss-Davis patent).

A supply of compressed oxygen is contained in the cylinders on the back. By means of a screw-valve situated at the side the oxygen is allowed to flow out in a steady stream into a strong rubber breathing-bag in front. From this two tubes lead to the mouth of the wearer. Both are fitted with mica valves, so that in the one oxygen gas can only pass inwards from the bag to the lungs of the man, and not in the reverse direction. In the other oxygen can only pass from the mouth of the man into the bag. The one tube serves to supply the wearer with a steady stream of fresh oxygen to breathe, while the other tube carries away the oxygen breathed out from the mouth. The bag contains caustic soda, which absorbs the carbon dioxide in the exhaled gas, and renders it fit for use again. Wearing such an apparatus, it is possible to work for two to three hours in a poisonous atmosphere and thus rescue men suffocating in an exploded mine or overcome by fumes in underground places where foul air collects. The gauge attached to the oxygen cylinders allows the wearer to read off how much oxygen is still contained in them.

(Illustrations from a pamphlet sent the author by Siebe, Gorman & Co., "Neptune Works," 187, Westminster Bridge Road, London, S.E.

Face page 176.

reached to within 300 feet of the door, but further he could not go, as he found that it was impossible to drag over 1000 feet of air hose after him, as it floated to the roof, and its friction against the rock and rough timbering offered greater resistance than he could overcome. After several efforts, even with two men passing the hose along, he abandoned the attempt, and was obliged to return to the shaft defeated.

The difficulty was solved by the " Fleuss " diving apparatus, which consisted of an ordinary diving suit carrying on its back in a steel cylinder a supply of compressed oxygen, thus making the diver independent of the long, cumbrous, heavy air tube. The diver breathed through a purifier containing caustic soda to absorb the carbonic acid or carbon dioxide which is being continually exhaled from the lungs into an air space contained in a waterproof jacket. Into this space oxygen gas was admitted from time to time from the cylinder of compressed oxygen, thus making the diver quite independent of any external supply. Mr. Fleuss, the inventor, first descended, but not being a professional diver was unsuccessful. Afterwards the diver Lambert made the attempt with the new apparatus, and after two journeys succeeded in closing the door. We can well imagine with what relief the anxious watchers at the shaft mouth at last saw the sudden appearance above the water of the bold adventurer after an absence of one and a half hours. How great a danger he ran may be appreciated from the fact that when Lieutenant Damant was testing this apparatus for the Admiralty Committee, and was deep under water, he suddenly swooned. The reason was that he had unwittingly let the oxygen percentage fall too low, and had fainted away without realising his danger. Before he could be got out of the water and freed from the apparatus his breathing had stopped, and he was apparently dead ; but the prompt application of artificial respiration soon brought him round. Had such an accident happened to Fleuss or Lambert when in the dark reaches of the tunnel nothing could have saved their lives. It is needless to say that in the thirty years which have elapsed since Mr. Fleuss invented this apparatus great improvements have been introduced, and this danger is now surmounted.

Oxygen has other uses besides those of restoring flooded tunnels and exploring exploded mines. It is one of the most valuable foods which can be given to an athlete undergoing violent exertion. For easing distressed breathing and the furious beating of the heart after a great muscular effort it is unsurpassable. The reason is not far to seek. A man at rest requires oxygen to burn the oxidisable matter in his blood and cells. When the man begins to work hard, oxidisation begins to take place at an increasing rate throughout all the tissues of his body, and may increase six or sevenfold. In order to meet this want, the lungs at once begin to draw in deeper and more rapid breaths, and at the same time the heart begins to pump more and more rapidly the blood into the tissues, and thus supply them with the increased amount of oxygen they require, the blood being, as above explained, the great oxygen carrier of the body.

In spite of all these efforts the body sometimes cannot get enough oxygen, and the muscles and heart become clogged with incompletely oxidised material. In consequence the limbs grow weak, breathlessness increases, and the heart is overtaxed by its desperate effort to pump in air rapidly enough to supply the furnace of the body. All this, however, may be altered by allowing the athlete to breathe, immediately before or after a great physical exertion, pure oxygen gas direct from an oxygen cylinder. The blood sucks in eagerly an extra supply of the gas, breathlessness vanishes, and an exhausted man is at once revived and sent back into the arena full of fire and energy. It is for this reason that oxygen is now supplied to boxers and footballers in the breathing intervals. Indeed, it is oxygen that the body naturally wants, and an artificial supply of pure oxygen will enable imperfectly trained men to perform feats which in its absence could only be performed by trained athletes. Moreover, a supply of oxygen immediately administered after a race will rapidly revive a "done" man and allow him to feel no injurious effects after the exertion.

One of the first men to obtain pure oxygen gas was Joseph Priestley. So long ago as 1774 he prepared it by heating red oxide of mercury by means of a burning glass. He, too, was

FIG. 32.—Dr. Leonard Hill administering oxygen.

(*From the cartoon by Charles Ambrose.*)

The oxygen is contained in a steel cylinder under a pressure of 100 atmospheres. From this it streams into a rubber breathing-bag and is inhaled through a tube passing from the bag into a cloth which covers the breather's head.

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the first to breathe this wonderful gas, which he called "dephlogisticated air." He says, "My reader will not wonder that, after having ascertained the superior goodness of dephlogisticated air by mice living in it, and other tests above mentioned, I should have the curiosity to taste it myself. I have gratified that curiosity by breathing it, drawing it through a glass syphon, and by this means I reduced a large jar full of it to the standard of common air. The feeling of it to my lungs was not sensibly different from that of common air, but I fancied that my breast felt peculiarly light and easy afterwards. Who can tell but that in time this pure air may become a fashionable article in luxury. Hitherto only two mice and myself have had the privilege of breathing it." How prophetically true were these last words of his have been seen above, for oxygen is already beginning to be used as a restorative and for many other purposes.

A large number of substances give off oxygen when heated. Among them may be mentioned red lead, mercuric oxide, potassium chlorate, barium peroxide, etc. It is usually prepared in the laboratory by heating potassium chlorate, when the following change occurs:

$$\underset{\text{Potassium Chlorate}}{2KClO_3} = \underset{\substack{\text{Potassium}\\\text{Chloride}}}{2KCl} + \underset{\text{Oxygen.}}{3O_2}$$

The illustration (Fig. 33) shows the usual method of preparing this gas as carried out in the laboratory. If pure potassium chlorate is taken the salt melts at 372° C. and immediately after this the oxygen begins to be rapidly evolved. If, however, the chlorate be mixed with only one quarter its weight of manganese dioxide, a black substance, the oxygen is evolved nearly twenty degrees C. lower. At the end of the experiment the manganese dioxide remains unchanged. Its action is "catalytic"; in other words, it causes an unlimited amount of decomposition in the neighbouring chlorate without itself undergoing any noteworthy amount of change—a very mysterious and as yet scarcely understood phenomenon.

The largest preparation of oxygen on record occurred on May 12, 1899, at Kurtz's Chemical Works at St. Helens in Lancashire, owing to an accidental heating of potassium chlorate. This substance is in itself harmless enough, but since it evolves readily on heating a large amount of pure oxygen gas, in which wood and even iron burn with the utmost fierceness, it may easily act as an inflaming if not an explosive agent. Now in this factory some hundreds of tons of chlorate were prepared weekly, and about 150 tons of the material packed in casks were lying stored in the building awaiting shipment. Somehow or other a spark from a cask which was being rolled into one of the crystallising rooms alighted on the wooden casing of a crystallising tank in which many tons of chlorate were lying. This wood, being soaked in dried potassium chlorate solution, was in a highly inflammable condition. Immediately a furious fire broke out, which flared upwards, and in a few minutes the roof of the building was blazing. Then followed a terrible and unforgettable scene. The fierce heat beating upon tier after tier of closely packed casks of chlorate caused an enormous volume of pure oxygen gas to come rushing forth. All the woodwork, being thus supplied with an atmosphere of pure oxygen, burned furiously, and the whole building was soon white hot, burning with the dazzling brilliancy of a blast furnace. At last, the oxygen being unable to release itself from its prison fast enough, the chlorate exploded. And what an explosion! Two stupendous swiftly-following thunder claps informed the busy town that a disaster had occurred, while a pall of black smoke rising upwards like a gigantic pillar announced the locality. The works were blown to pieces. Buildings and storehouses were levelled to the ground. Great iron travelling cranes were smashed like matchwood. The top of a neighbouring gasometer was torn to pieces, and a quarter of a million cubic feet of gas rushed flaming forth into the air. The flying burning fragments of timber had caused it to ignite, and there was seen the appalling spectacle of a vast column of flame 500 to 600 feet high ascending to heaven with a mighty roar. So terrible was the shock that the ground trembled like an

earthquake for miles around, houses were blown down, and windows miles away were smashed by the gigantic sound waves, while the whole town was plunged into a panic. The passengers of a train which had just steamed into the station had an alarming experience. Although a considerable distance away from the scene of the explosion, the carriages

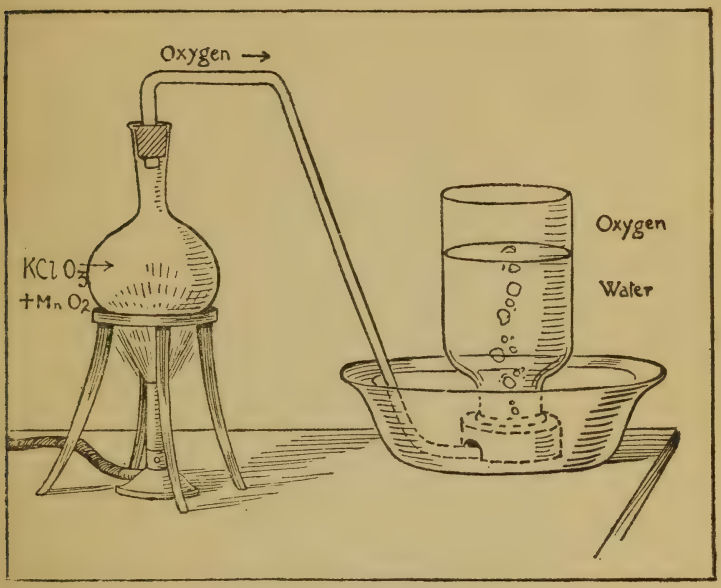

FIG. 33.—Preparation of Oxygen Gas by Heating Potassium Chlorate. Potassium chlorate, mixed with one quarter of its weight of manganese dioxide, is placed in the flask and gently heated. Oxygen gas is rapidly evolved and is collected over water in the glass bottle.

seemed to be lifted from the metals and the windows of the station buildings were smashed as if some one had dealt them a sudden blow. Five men were killed outright, while a score or more were badly injured by flying débris. The loss of life would have been fearful had it not been for the fact that, fearing explosion, the workmen had been all hurried away the instant the fire broke out.

Probably nearly one and a half million cubic feet of pure

oxygen gas was thus suddenly poured into the air. It was simply the repeating on an enormous scale of one of the experiments carried out by every beginner in chemistry, namely, the preparation of oxygen by heating potassium chlorate. Few who have carried out this experiment many times have ever realised the consequences of repeating it on such an enormous scale. Once the mighty forces which lie locked up in every chemical compound have got out of control disaster in some form or other is always sure to follow.

The air consists of oxygen diluted with about four times its volume of nitrogen, and it is from this practically limitless source that oxygen gas is now manufactured. The difficulty, of course, is to separate it economically from the admixed gases. When liquid air is allowed to evaporate, the nitrogen, being the more volatile constituent, boils away more rapidly than the oxygen, and the residual liquid becomes continually richer in the latter element. This may be shown easily by placing some liquid air in a suitable vessel and allowing it to evaporate. At first the vapour which rises from the liquid air is practically pure nitrogen, and extinguishes a glowing wood splinter. Afterwards it gives place to oxygen, and the vapour will now cause the same splinter to burst into flame.

It is quite possible to get a richness of, say, sixty per cent. of oxygen in this way, but when the evaporation is pushed beyond this limit, the vapours which pass off contain so much oxygen that in the end when the purity is high the liquid itself is almost exhausted, and though what remains is practically pure oxygen, its quantity is so minute as to render the process useless for commercial purposes. It was not until 1902 that Linde perfected a process which has enabled oxygen sufficiently pure to be obtained on a commercial scale by liquefying air. At the present time in England alone something like 100,000 cubic feet of oxygen are produced daily by this method, and no doubt this production will in time increase as the use of oxygen augments until it will swell into an immense industry.

Linde carries out the mechanical separation of air into

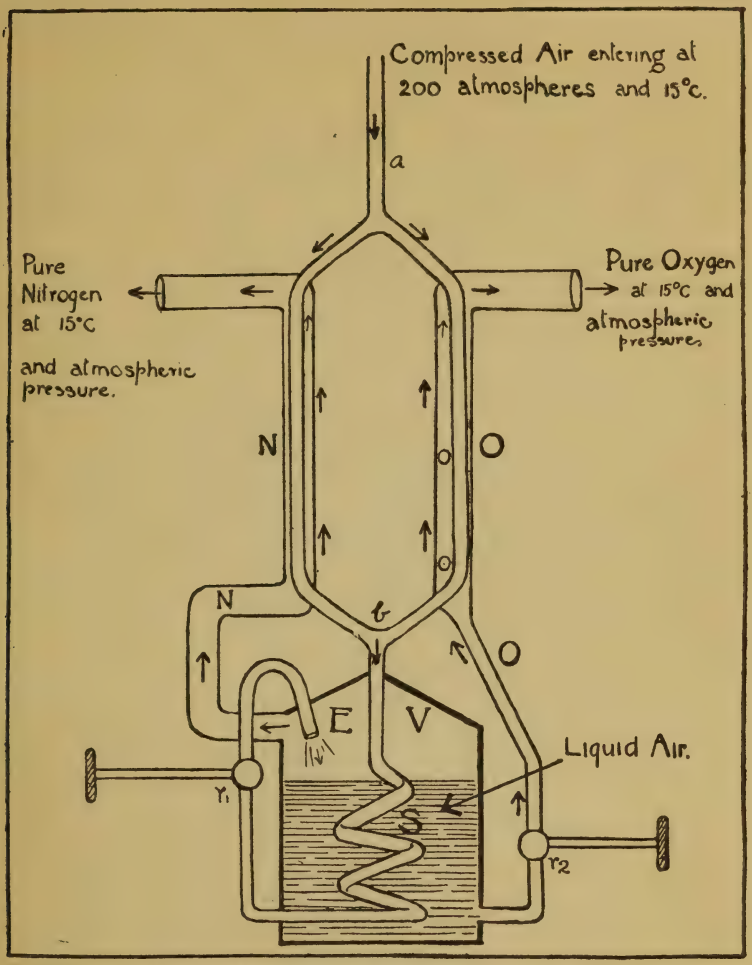

FIG. 34.—Linde's Apparatus for separating air into pure oxygen and nitrogen.

oxygen and nitrogen as follows: * Air compressed to 200 atmospheres enters a tube which divides at *a* (Fig. 34) into two

* In connection with this the reader should turn back and read the account of the Linde Process for liquefying the air, as described in Chapter VII.

counter-current tubes which unite again at *b*; it then streams through a spiral S in the collecting vessel V, and then passes through the regulating valve *r*, and expands at E into the collecting vessel. By the expansion great cold is produced, and the chilled gas then streaming up the counter-current tubes N and O cools down the incoming stream of air which is coming down pipes in their centres. The air thus cooled in its turn expands at E and produces a still greater degree of cold, which then streams off through N and O, and still further cools down the air in the interior tubes. The effect is cumulative, and ultimately the air expanding at E becomes so cold that part liquefies, and dropping into the chamber V partially fills it. But another part (principally the more volatile nitrogen) passes up through the counter-current tube N and leaves the machine. The spiral S also plays a most important part, since by its means the continual stream of compressed air entering the apparatus gives up nearly all its heat to the liquid air in the vessel and causes it to continually boil and evolve nitrogen vapour, leaving more or less pure oxygen behind. The regulating valve r_2 allows the liquid oxygen left behind in V to pass out of the chamber in such a manner that the level of the liquid can be altered as required, and thereby the quantity of heat imparted to it by the inrushing air in the spiral varied so as to maintain the rate of boiling of the liquid in V at any given speed, and so obtain oxygen of any given degree of purity. The liquid streaming out through r_2 (more or less pure oxygen) passes into the counter-current tube O, and takes up from the entering air the heat which is necessary to cause evaporation and to neutralise its temperature. If things are properly regulated, the entering air gives up almost all its heat to the outstreaming oxygen and nitrogen, and these latter gases pass out into the atmosphere in a separated condition at temperatures only very slightly lower than that at which they entered. In this manner there is little loss of heat, and consequently oxygen can be produced quite cheaply. From one ton of coal burnt in the steam engine generating power something like one ton of oxygen and four tons of pure nitrogen can be obtained.

The apparatus that we have sketched above only illustrates

the principle of Linde's invention. In practice extensive coiling and fractionating apparatus is required in order to produce a complete separation. The straight tubes in our diagram are replaced by long spirally-coiled tubes hundreds of yards long. Naturally all the tubing must be most carefully packed in wool or feathers in order to prevent external warmth filtering through and heating the cold gases. The reader who requires a more extended account of these wonderful new methods may consult Linde's original patent, No. 14,111 of 1902. The Linde plant is also very clearly and concisely described in a book on refrigerating machinery recently published by Professor Ewing.*

No one can contemplate the enormous masses of oxygen which occur in Nature without a feeling of astonishment. It surrounds us on all sides. Millions upon millions of tons of it blow in our faces in the winds which rush over the surface of the earth. The whole crust of our globe is saturated with it. Originally the whole of the 1,200 billion tons of oxygen in the air was locked up in the state of chemical combination, and it was only set free by cosmic forces working for untold ages. And thus it comes about that the quantity of oxygen occurring in the atmosphere, vast, indeed, as it seems to us, is negligible when compared to the enormously greater masses which occur chemically combined in the earth's crust. The chief mass of the latter is composed of very old crystalline rocks, the silicates, and these contain forty-four to forty-eight per cent. of oxygen. The percentage is still greater in sedimentary rocks like limestone, chalk, marble, dolomite, where it sometimes rises from forty-eight to fifty-two per cent. Thus we see that all the millions upon millions of tons of hard rocks which go towering up to heaven in mighty mountain ranges and cliffs are nearly half oxygen by weight! When we think of the stupendous mass of rock and earth lying round the whole earth and extending into its depths for miles, the amount of oxygen thus stored up about us is seen to be almost unthinkably vast. I suppose the amount could be calculated in tons weight, but it

* "The Mechanical Production of Cold," by J. A. Ewing, F.R.S. Cambridge University Press, 1909.)

would form an almost unmeaning array of figures. But oxygen not only forms nearly half the weight of the soil and rocks, it forms almost the entire bulk of the sea. Out of every 100 tons of water no less than eighty-six tons are oxygen. The amount of oxygen thus stored up in the stupendous mass of sea-water which girdles this planet with a garment of green is immense, and enormously exceeds the amount of free oxygen in the air. Hence we see that important as the oxygen of the air seems to us, it is only, so to speak, a mere accidental trace, an infinitesimal residue, left over in constructing the giant building of the earth. Since man and all animals depend essentially for life and existence upon the oxygen of the air, these facts give us an insight into the general insignificance of the animal world in the design of Nature. Undoubtedly we attribute too much importance to living matter, as is seen by the vast bulk of non-living as compared to the infinitesimal trace of living matter in the universe. It must be boldly confessed that Science, in spite of her great discoveries, is completely in the dark as regards the object and drift, the why and wherefore, of all the great workings of Nature. In Tennyson's beautiful words :

> " The drift of the maker is dark,
> As Isis hid by the veil ;
> Who knows the ways of the world,
> How God will bring them about ? "

Oxygen forms, according to a careful calculation of Clark, 47.3 per cent. of the earth's crust, and is by far the most abundant and widely distributed element in the outer parts of the earth. On the other hand, it occurs either not at all, or only in traces, in the intensely heated core of the earth, and so is probably not the most abundant element of the globe.

For a long time oxygen could not be discovered in the sun, nor in the stars, and men were already beginning to flatter themselves that by a special favour of the Creator this planet had a monopoly of free oxygen ; but, as is always the case with such self-laudatory dogmas, it was soon found that this was not the case, for it has been recently shown that it exists free in certain stars. In general, however, oxygen emits a light which makes it very difficult to detect in the presence of

large numbers of other elements. The absence of indications of its presence in the light of many stars probably does not mean that it is really absent, but merely that its light is hidden or suppressed. In the real oxygen stars it must occur in appalling excess, and when such stars cool down they may well form worlds surrounded with an atmosphere of nearly pure oxygen gas. Doubtless even at the present time there go circling round them planets whose atmospheres are practically pure oxygen, and which, therefore, would be capable of exhibiting all the wonderful effects of combustion in pure oxygen to which we have alluded in a previous page.

Under the influence of an electric discharge oxygen passes into a most remarkable modification called ozone, whose molecules consist of three oxygen atoms. This is very chemically active, and at a low temperature condenses to a deep blue explosive liquid.

On our earth almost all the free oxygen occurs as ordinary oxygen gas, *i.e.*, as diatomic oxygen, only traces of monatomic and triatomic oxygen being met with; but the reader must not conclude that this is the case everywhere throughout the universe. On other planets where other conditions prevail most of the free oxygen may occur as ozone, and our ordinary diatomic oxygen may appear to the inhabitants of these bodies as a rare and unstable modification. At low temperatures and pressures the stable form of oxygen is ozone, especially in the presence of moving charges of electricity. Now vast discharges of electricity are ever occurring in the air. The aurora borealis and the numerous thunderstorms which occur over the whole earth are but slight external manifestations of the tremendous silent discharges continually rushing through the upper regions of the atmosphere. In fact, the whole earth is bathed in a mighty torrent of negatively charged particles shot out from the sun. It has been for ages revolving in this immense stream of negative electricity, and consequently possesses a negative potential of a billion volts and an enormous charge of free negative electricity. On other planets these electrical discharges may be on an incomparably greater scale.

Now, if such a planet possessed an atmosphere of oxygen

at a low temperature and pressure, the whole of this element would pass ultimately into the state of ozone, as Goldstein showed in 1893. This opens out some amazing possibilities. The ozone would thus act as a trap for storing up part of the electrical energy flowing past the planet, and on such a world it would perhaps condense to great indigo-blue seas, while blue clouds and mists of ozone vapour would float about in its atmosphere. The sun, if one existed, would shine through a sky of a dark blue colour and would probably itself look blue. Indeed, the whole surface of such a world would look like a landscape viewed through blue glass. Strange forms of life, too, would conceivably exist, for the great chemical activity, combined with the great energy stored up in ozone, could support the energy transformation which is always a concomitant of vital action. For the slow passage of ozone into ordinary oxygen in the bodies of such creatures would supply vital energy to them in much the same way that the slow passage of oxygen into carbon dioxide supplies energy to us. Both chemical changes are accompanied by the evolution of much heat. Perhaps, indeed, in the ages still to run, when the world is much colder and darker than it is at present, and the seas are all frozen into solid rocklike masses of ice, most of the oxygen of our atmosphere will have become ozone, and the only living creatures still existing would be some strange beings breathing and living on this ozone in the way suggested.

This opens out still other curious possibilities. The ozone which thus gradually accumulated could cause great catastrophes. The stupendous energy stored up in the seas and vapours of ozone might be suddenly liberated by the impact of a stray meteorite flashing down from the heavens, or by a volcanic eruption flaring forth from the bowels of the earth. There would then result a vast explosion, extending all round the world and annihilating in a second in a vivid flash of flame every living creature. The ozone would thus be suddenly and entirely transformed into oxygen, which would in the course of long ages again be transformed into ozone by the slow inpourings of electrical energy, and this again would ultimately blow up. Such a planet under these conditions would thus be the scene of gigantic periodic explosions.

CHAPTER IX

THE ELEMENT NITROGEN

THE element nitrogen, the seemingly inert constituent of the atmosphere, of which it forms more than four-fifths by volume, is of extraordinary importance to man. Besides being the parent element of the innumerable drugs, medicines, dyes, and explosives used in our complex civilisation, it is also an essential constituent of all living matter, which indeed owes its sensitiveness and liability to change to the presence of unstable nitrogen compounds. In many respects it stands apart from the other elements. Its great chemical inertness towards the more common and usual elements has in the past prevented it from being stored up to any considerable extent in the interior of the earth. It occurs free in the atmosphere merely because it is an unusable residue left over in the building up of the framework of the earth. Had nitrogen been to any important degree a chemically active body, then, as has happened in the case of nearly all the other elements, it would long ago have been fixed, chemically combined, in the soil and rocks, and there would have been at the present time scarcely any atmosphere to speak of for us to live in.

However this may be, we must now give a brief account of the preparation and properties of this remarkable element, and at the same time we will review the great economic problems opened within the last few years by the possibility of its partial exhaustion in the soils of civilised lands.

If ordinary air be passed through a red-hot tube filled with copper turnings, a sample of impure nitrogen will be obtained, because the copper removes all the oxygen from the air, thus:

$$\underset{\text{Copper}}{2Cu} + \underset{\text{Oxygen}}{O_2} = \underset{\text{Copper Oxide,}}{2CuO.}$$

There then issues from the end of the tube a mixture of nitrogen and argon, both inert gases which resemble each other and are difficult to separate by purely chemical means. They can, however, be separated by liquefying the gas and then allowing it to boil. The nitrogen, being more volatile than argon, boils away first, and may be collected. The argon remains behind in the higher boiling part. Usually, however, we do not trouble to free nitrogen from its contained argon, since these elements do not interfere with each other's reactions.

A very simple way of removing oxygen from the air is to burn phosphorus in a closed bell jar over water. The phosphorus (a piece about the size of a pea will do) is placed in a little porcelain basin and lighted by touching it with a piece of red-hot wire. The bell jar is then quickly placed over the basin and kept there until the phosphorus has used up all the oxygen, according to the equation :

$$\underset{\text{Phosphorus}}{4P} + \underset{\text{Oxygen}}{5O_2} = \underset{\text{Phosphorus Pentoxide.}}{2P_2O_5}$$

The gas remaining in the bell jar after the white clouds of phosphorus pentoxide have dissolved in the water is nitrogen mixed with argon.

For industrial purposes all these methods are too dear, and the gas is manufactured from the air by the Linde Process already described under "Oxygen" in Chapter VIII.

The gas obtained by any of these processes is not distinguishable by our sight from ordinary air, being colourless, odourless, tasteless, and invisible. It is distinguished, however, from air by a remarkable quality. It allows nothing to burn in it. A light plunged into it is quenched as suddenly as if it were plunged into water. At ordinary temperatures no substance appears to have any appreciable chemical action upon it. The element seems dead. Now note some very curious consequences of this. The spectroscope shows us that it occurs in space. All stars, all nebulæ, and most planets contain it. In nebulæ it occurs in great cloud-like masses, invisible to our eyes, and stretching for millions of

miles through space. These dark masses of gas only accidentally, so to speak, reveal the presence of nitrogen in them when they gleam with the mysterious electrical fires which so often illuminate their exteriors. The atmospheres of the planets Mars and Venus are in all probability, like our own, composed principally of nitrogen gas; for while oxygen and the other elements have for the most part been absorbed and combined chemically in their interiors, the nitrogen on account of its chemical listlessness has been left untouched for ages, and still blows free in the winds and breezes which circulate over their mountains and valleys, being in the same condition now as it was when these worlds were formed hundreds of millions of years ago.

In order to realise more forcibly the properties of this element nitrogen, I wish the reader to picture the condition prevailing in a world whose atmosphere consisted solely of nitrogen gas. It is perhaps going too far to say that the surface of such a nitrogen planet must be a vast waste of sea, sand, and rock, a waste untenanted by any living thing; for it is not inconceivable that forms of life would evolve on it which are capable of breathing nitrogen. Even on the earth at the present time many bacteria, some plants, and most mosses possess the capacity of slowly absorbing nitrogen. Under such circumstances as those we have here pictured this capacity could possibly develop by evolutionary means in a wonderful way, and on landing on such a planet we might find it covered with forms of life flourishing under conditions which would be fatal to creatures from this earth.

However this may be, we may assert with certainty that no man or beast, if placed on the surface of the planet, could exist even for a minute in this atmosphere. The dead listless air would choke out their lives almost immediately—not because nitrogen is in any way poisonous in the sense that coal gas is, but merely because it is so chemically indifferent that it cannot support the combustion required for our lives. Men and animals require oxygen and are indifferent to nitrogen.

Perhaps, however, the most extraordinary thing of all

on such a planet would be the incombustibility of everything which burns freely in the atmosphere of our earth. No matter how hard we tried no candle nor oil lamp could be lighted, and paraffin oil could be poured upon white-hot coal without catching fire! Indeed, the oil would merely serve to quench the heat of the coal just as water would! Our cheerful coal fires would be an impossibility on such a planet, for coal would be as incombustible as gold or stone. It would, in fact, be a perfectly useless mineral, and not, as on our earth, the source of untold wealth and power. It is true that by its destructive distillation gas could be obtained, but as this would be as incombustible as nitrogen itself, it too would be quite useless.

Thus my readers will see that at ordinary temperatures nitrogen is seemingly inert and dead; and yet this gas is not dead. In it are slumbering mighty forces, titanic energies, which await only the magic art of the chemist to manifest themselves in the shattering power of modern explosives.

The mighty energies locked up in this gas are, indeed, partially liberated at high temperatures and under the influence of electricity. Thus, although at ordinary temperatures nothing will induce oxygen to unite with nitrogen, at a white heat, and in the path of a high tension discharge of electricity, it will unite with it so furiously that it produces a flame hot enough to melt, and even to boil, platinum, one of the most infusible of metals. When those immense electric discharges which constitute a lightning flash oscillate through the air in a mighty arc of miles in length, the nitrogen and oxygen in their paths are rendered white hot and combine. The path of a flash of lightning is thus occupied for a short time afterwards with a great flame of burning oxygen and nitrogen, and the "sulphurous smell" noticed after its near passage is probably due merely to oxides of nitrogen thus produced.

Indeed, many elements at a high temperature possess the power of uniting with nitrogen, forming compounds called nitrides. The metals magnesium and calcium will actually glow if heated in the gas. The nitrides of phosphorus, silicon,

boron, titanium, and wolfram are almost as stable as the corresponding oxides.*

All living matter requires nitrogen. The continual restless movement of protoplasm, its growth and decay, is occasioned by this element. Indeed, without nitrogen there can be no life. Deprive animals or plants of food containing nitrogen and they sicken, fade, and die. But this nitrogen must be combined. Animals cannot at all, and plants can only with excessive slowness, absorb it when in the free state. The vast ocean of free nitrogen, which forms four-fifths of the air which blows in our faces, maintains in a chemical sense an almost completely listless, useless lethargy. Before the nitrogen can be rapidly and usefully assimilated by living matter it must be "fixed" by combining it with other elements.

An account will now be given of the various modern attempts to solve the problem of transforming in large quantities the free and useless nitrogen of the air into the fixed and useful kind. This is a problem of stupendous importance to the whole human race. Solve it, and plenty and prosperity will smile throughout our planet. Fail to solve it, and there is the certainty that in a few years starvation will stare multitudes in the face, that hunger and want will stalk through all civilised lands, that revolutions will surge through all our towns and cities.

This statement may seem sensational and alarming, but how true it is was amply proved by Sir William Crooks in his famous address to the British Association in 1898.† For every speck of living matter, even as it lives, is decomposing; and in so doing it liberates and eliminates the nitrogen stored up in its substance. The very condition of life seems change. And the atoms of nitrogen which occur in all living matter form the centres of instability from which the continual breakdown proceeds. Each impulse which flashes along a nerve represents the almost explosively rapid decomposition of a train of nitrogen

* The reader will find a full discussion of these and allied facts in the author's work "Researches on the Affinities of the Elements."

† "The Wheat Problem," by Sir W. Crooks. *Chemical News* Office, 16, Newcastle Street, London, E.C.

compounds scattered along it. Every muscular contraction, every weight lifted, every movement of our body, every feeling of pleasure and pain, represents the decomposition of so many millions of molecules of nitrogen compounds. When we consider the countless numbers of nerves, scattered like complex systems of telegraphic wires through every part of the body, and coiled and recoiled a million times in complex networks in our brains, and then reflect that along each of these are continually speeding to and fro rapidly moving waves of chemical decomposition, it can be seen easily that the quantity of nitrogen compounds decomposed each hour in our bodies, and eliminated ultimately in our perspiration and excreta, is very considerable. This continual waste of nitrogen must be made good, or the animal or plant will sicken and die. Men and animals restore this nitrogen wastage by eating it in the form of animal and vegetable food. Every pound of meat we eat, every loaf of bread, represents so much combined nitrogen which passes into our bodies. Now the plants and the animals we eat depend ultimately upon the soil for almost every trace of nitrogen that they contain, and the soil in its turn has won its nitrogen from the air, painfully and laboriously, during the untold ages of the past, by vast never-ceasing cosmic processes of extreme slowness. The lightnings of a billion storms have combined it in the air; the rains of hundreds of millions of years have washed it combined from the air into the soil; billions upon billions of microbes in plants and in the soil have ceaselessly absorbed it during unnumbered ages; consequently the nitrogen combined in our soil represents the united efforts of all Nature working continually for unthinkably vast periods of time.

Even the valuable nitrogen-containing substances we employ in our civilisation, the rich dyes, the powerful medicines, the terrible explosives, are all in the same perilous position of depending ultimately upon the soil for their nitrogen. The nitrogen that we see dispersed instantly in the bright flash of a battleship's broadside has taken millions of minute organisms, laboriously working for centuries, to win from the atmosphere!

What do we do with the earth's precious store of nitrogen ? We filch it from the soil immensely faster than it is restored by natural processes ; and the land grows sick and barren, and refuses to grow our crops. Vast tracts of land, in Sicily, in the broad plains of Northern Africa, in the great valley of the Euphrates, once the richest corn-producing regions of the world, have within historical times grown barren and sterile largely owing to this cause.

Every one knows what must be done to cure such land. We must impregnate it with manure or fertiliser. In other words, we must mix with the soil substances containing fixed nitrogen which the plants can utilise in building up materials for our food. In the olden days natural manure was sufficient to meet the demands of a thin population ; but in these days of rapidly increasing civilised man the natural manures of the world are far too small in quantity to be of any use. Men were long ago forced to the employment of artificial fertilisers. Indeed, there exists several sources of available nitrogen on the earth. For example, large amounts of nitrogen are obtained in the form of ammonium sulphate in the distillation of coal in the process of gas-making. This nitrogen once coursed through the bodies of plants and animals which passed away millions of years before man trod the earth. After being buried for untold ages it once again sees the light of day, and being used for manure, finds its way into the bodies of plants and finally into our own bodies, so that the very nitrogen now in our own bodies may once have throbbed in the huge body of some great reptile inhabiting the swamps and valleys of the Mesozoic Age millions of years ago ! Little did such animals dream of the ultimate destiny of their nitrogen, as little, perhaps, as we dream of the ultimate destiny of ours millions of years hence ! The sober facts of Science are far stranger than any fairy tale.

However this may be, the world's production of ammonium sulphate was in 1900 only 500,000 tons—a quantity much too small to meet the demands of agriculture ; nor does the quantity seem to be greatly extendable. There is, in fact, but one substance occurring in sufficient quantity to be used as a world-wide manure, and that is sodium nitrate

($NaNO_3$), or Chili saltpetre. This substance occurs native over a narrow band of the plain of Tamarugal in Chili. In this rainless district for countless ages the continual absorption of atmospheric nitrogen by the soil, and its conversion into nitrate by the slow transformations of billions of nitrifying organisms, has been steadily proceeding. Yet even these huge supplies of combined nitrogen are limited. There must surely come a time, and that at no distant date, when these fields are exhausted. We are using up the nitrate far more rapidly than it is being formed. In 1860, 68,000 tons of saltpetre were withdrawn; in 1870, 182,000 tons; in 1880, 225,000 tons; in 1890, 1,025,000 tons; in 1900, 1,453,000 tons; in 1906, it was 1,600,000 tons, and we may expect that in 1910 something like 2,000,000 tons will be mined. Of the amount yielded in 1900, about one quarter passed into the thousands of nitrogen compounds used in our civilisation, the other three-quarters into food through use as manure. Thus, European and American agriculture is almost completely dependent upon a tiny strip of land in a remote South-American Republic; and they pay over £12,000,000 a year for their present import of nitrate—an oppressive and growing burden. Moreover, were by some internal catastrophe the export to cease suddenly, famine and insurrection would follow as surely as night follows day.

Within thirty years these beds will be exhausted; and a year or two after that famine will be upon us.

All this was pointed out in 1898 by Sir William Crooks; but he did more than point out a coming danger—he showed how it could be averted. His suggestions are even now being carried out in different parts of the world and promise to turn a threatened misfortune into an actual blessing, as we shall presently see.

There exists in the atmosphere an almost inexhaustible supply of nitrogen—about 3,980 billion tons. Every square yard of land has about seven tons of nitrogen lying over it; but all this nitrogen is "free," and therefore useless for manuring purposes. Combine it, or "fix" it, and plants can absorb it directly into their tissues. The nitrogen of

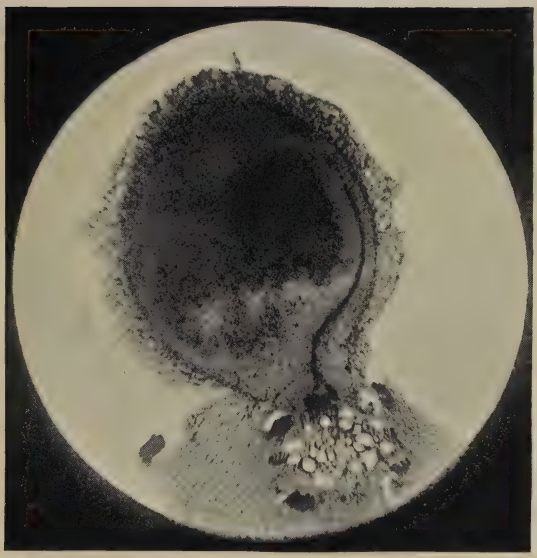

FIG. 35.—Nodule of a Bean cut open.

These nodules are veritable cities of nitrogen-assimilating organisms. Magnified about 40 diameters. Plant 4 weeks old. Photograph by Dr. Hutchinson, lent by Mr. John Golding, F.I.C., F.C.S., Agricultural College, Kingston, Derby.

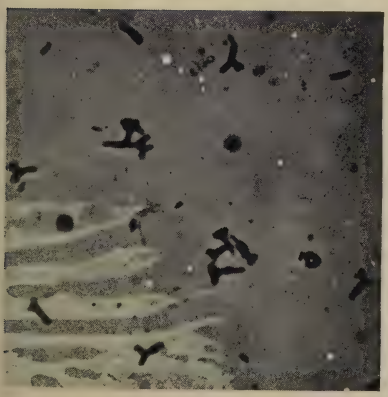

FIG. 36.—Nitrogen assimilating Organisms in a Bean Nodule.

Magnified 950 diameters. Photograph by Dr. Hutchinson, lent by Mr. John Golding, F.I.C., F.C.S., Agricultural College, Kingston, Derby. These wonderful organisms have the power of breaking down and combining with the molecules of nitrogen of the air, thereby enriching the soil on which they grow.

FIG. 37.—(1) No combined Nitrogen. (2) Inoculated with crushed nodule of a bean.

This photograph shows very well the vigorous growth caused under suitable conditions in plants impregnated with nitrogen-assimilating organisms. Photograph by Dr. Hutchinson, lent by Mr. John Golding, F.I.C., F.C.S., Agricultural College, Kingston, Derby.

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the air over a single square mile would, if converted into nitrate, be worth £25,000,000 and supply the whole world with enough manure to last some years !

Hence a method for fixing the atmospheric nitrogen cheaply and efficiently would be one of the greatest discoveries of Science, and recently this fixing has been done in more ways than one.

Some years ago Hellriegel discovered that leguminous plants like clover, beans, and peas, have their roots covered with tiny pimples which are veritable cities of " nitrifying " organisms, that is to say organisms which possess the power of absorbing directly the free nitrogen of the air and combining it in their tissues. Hence these organisms are continually performing a chemical feat which is far beyond our power. Silently and unceasingly, at ordinary temperatures, and without the passage of powerful electrical discharges, they are continually withdrawing the nitrogen of the air, combining with it and storing it up in their tissues. This is only another illustration of the fact of how mysterious are the processes going on so swiftly in the laboratory which constitutes a living cell, and how vastly superior is its chemical processes to those which we with infinite pain and trouble, using high temperatures and strong chemical reagents, carry out in our laboratories. Each tiny speck of living matter is a seething universe of atoms, rushing to and fro, driven by mighty unknown forces, forces emanating from the immeasurable ocean of intra-atomic energy incessantly in play within the very atoms themselves. Vitality, indeed, seems to be the manifestation of forces, stupendous and incessant, governing a world beneath the atom. No wonder then its chemical operations can often not be imitated by the crude methods of the chemist !

For a long time it was thought that these bacteria could only flourish on leguminous plants, but recently Professor Bottomley has shown that they were not specific in their character and could be trained for use with other species of plants. Here arises a valuable possibility. By suitably infecting poor earths with these nitrogen absorbing bacteria a farmer can cause it to increase gradually its content of

nitrogenous compounds and thus become rich and fertile soil. In 1896 Nobbe and Hiltner brought their microbe into a commercial portable form under the name "Nitragin," and now, after many preliminary failures, their measure of success has been so great that to-day several manufactories are perfecting their processes for the wholesale production of nitrifying microbes. There are hundreds of different sorts of these nitrifying organisms, and even now research is feverishly investigating them. There can be no doubt that by their aid we can restore to the soil the fertilising nitrogen which in the past we have so extravagantly wasted. Indeed, we are here merely imitating Nature, hastening her slow processes to meet our wants.* This process of imitation is now being carried out in still another direction, and, perhaps, with even greater success.

We have seen that the lightning flash burns the air in its path into oxides of nitrogen, which, when washed down by the rain into the soil, quickly become fixed as nitrates. Not only lightning, but also the silent electric discharges which are always taking place in the atmosphere cause the oxygen of the air to combine with the nitrogen to form nitrites and ammoniacal salts. Something like 400 million tons of combined nitrogen thus fall every year into the earth or sea as the result of this electrical action,† or more than a thousand times more than is at present artificially supplied by Chili saltpetre, which in 1905 amounted to 260,000 tons of combined nitrogen.

Lightning is but a vast electric spark; hence by flashing through the air electric sparks we can cause the air to burn and produce nitric acid and nitrates. So long ago as 1892 Sir William Crooks exhibited at one of the Soirées of the Royal Society an experiment on "The Flame of Burning Nitrogen." By passing a strong induction current between

* For further information the reader should see "The World's Work," Sept., 1907, p. 372. Reference may also be made to the valuable papers of Mr. John Golding, F.I.C., F.C.S. His Presidential Address, "Adaptation," to the Nottingham Naturalists' Society, 1907-8, gives a complete account of the question.

† Arrhenius, "Das Werden der Welten," p. 130 (1908).

FIG. 38.—The Works at Notodden, where fertilising nitrates are produced from the atmosphere.

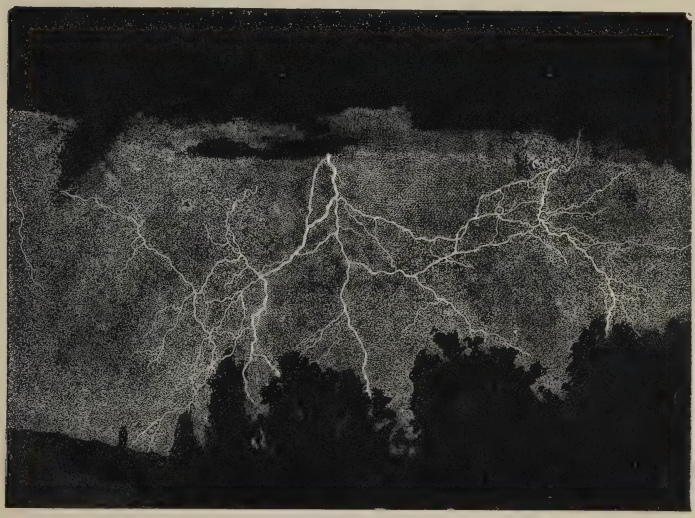

FIG. 39.—Lightning.

Although it sometimes causes disaster, lightning is of great value to all living things, for by its means nitrogen gets into the soil in a form suitable for assimilation by plants. The immense heat of the flash burns up the air in its path, causing the oxygen and nitrogen to unite to form nitrates and nitrites which are washed down by the downpouring rain into the soil. More than 400 million tons of nitrogen are combined yearly in this way. Most of the combined nitrogen in the soil and in living things has been obtained from the air in this way.

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terminals he showed that the air took fire and continued to burn with a powerful flame, producing nitrous and nitric acids. With truly prophetic words he said,* " This inconsiderable experiment may not unlikely lead to the development of a mighty industry destined to solve the great food problem." How his words have been fulfilled will be seen in the sequel.

The first successful nitrate factory was set up by Professor Birkeland and Dr. Eyde at Notodden in Norway. Here amid all the magnificent scenery of the land of hills and dales, by the still waters of a lake which provides water carriage all the way to Christiania and Hamburg, and on the banks of a rushing torrent of water which supplies abundant power to drive the great dynamos which generate the electric current, may be seen a little group of houses, the nucleus, perhaps, of a great manufacturing town of the future, where the fertilising nitrates are directly produced from the atmosphere. A rough diagram of the apparatus is shown in Fig. 41. By means of a powerful alternating current of 3000-5000 volts a powerful electric arc is formed between two copper electrodes placed in a stream of air. The electrodes are hollow and are traversed by a stream of cold water to prevent them fusing in the heat produced. The terminals of the electrodes are placed at a distance of eight mm. to one cm. apart, or between one-third and one-half inch apart. The arc is deflected at right angles to the direction of the electrode by means of a powerful electro-magnet placed in such a way that the terminals of the copper electrodes are in the middle of the magnetic fields as shown in Figs. 48 and 49. Instantly a great roaring rotating disc of immensely hot flame of burning nitrogen gas, six feet in diameter, forms between the electrodes. The gases from the flame are pumped off. They contain two-thirds per cent. of nitric oxide (NO) formed thus:

$$\underset{\text{Nitrogen}}{N_2} + \underset{\text{Oxygen}}{O_2} = \underset{\text{Nitric Oxide.}}{2NO}$$

The gases are cooled down gradually and the nitric oxide is converted into nitrogen peroxide by allowing it to mix with

* Presidential Address to the British Association, 1898.

air in a reaction tank of sheet iron enamelled on its inner surface. The equation is:—

$$\underset{\text{Nitric Oxide}}{2NO} + \underset{\text{Oxygen}}{O_2} = \underset{\text{Nitrogen Peroxide.}}{2NO_2}$$

From this reaction tank the nitrous gases pass through dripping nitric acid and up water towers, where they meet with dilute caustic soda or milk of lime. A mixture of sodium or calcium nitrate and nitrite is then formed, according to the equations:—

$$\underset{\text{Nitrogen Peroxide}}{2NO_2} + \underset{\text{Water}}{H_2O} = \underset{\text{Nitric Acid}}{HNO_3} + \underset{\text{Nitrous Acid.}}{HNO_2}$$

$$\underset{\text{Nitric Acid}}{HNO_3} + \underset{\text{Nitrous Acid}}{HNO_2} + \underset{\text{Caustic Soda}}{2NaOH} = \underset{\text{Sodium Nitrate}}{NaNO_3} + \underset{\text{Sodium Nitrite}}{NaNO_2} + \underset{\text{Water.}}{H_2O}$$

$$\underset{\text{Nitric Acid}}{2HNO_3} + \underset{\text{Nitrous Acid}}{2HNO_2} + \underset{\text{Milk of Lime}}{2Ca(OH)_2} =$$

$$\underset{\text{Calcium Nitrate}}{Ca(NO_3)_2} + \underset{\text{Calcium Nitrite}}{Ca(NO_2)_2} + \underset{\text{Water.}}{2H_2O}$$

The mixture of calcium nitrate and nitrite can be used directly as a manure.

In practice the alternating current disc-flame is enclosed in a special furnace lined with fire brick and furnished with a metal casing. The fire chamber of the furnace is narrow —from five to fifteen cms. wide—made partly of perforated chamotte, air being conveyed to the disc-flame, in an evenly distributed supply, through its walls. The air is driven at the rate of 3,000 feet per minute into the central region on both sides of the flame by gentle pressure from a Root's blower; and after passing in a radial direction arrives at a peripheral channel, whence it is conducted away. This process is still limited in extent, because sodium nitrite from Chili is still so cheap. When, however, the nitrate fields become exhausted, and at the same time the population of the world has greatly increased, the method will probably grow enormously in

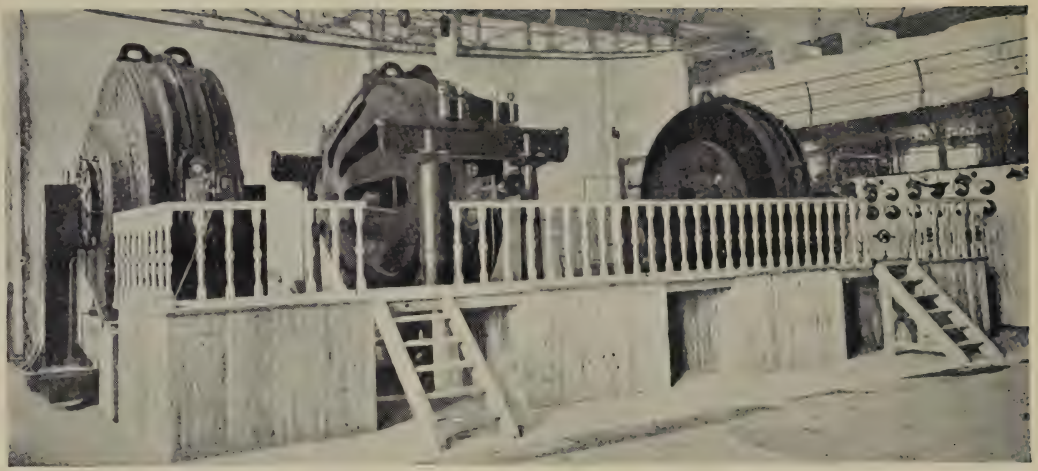

FIG. 40.—Group of Birkeland-Eyde Electric Furnaces, each of 800 horse-power.

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value and may later become a vast industry employing thousands of workmen all over the world.*

Another process for fixing atmospheric nitrogen, entirely different in principle from the foregoing, has been introduced by Prof. Franke of Charlottenburg. He found that when atmospheric nitrogen is passed over red-hot calcium

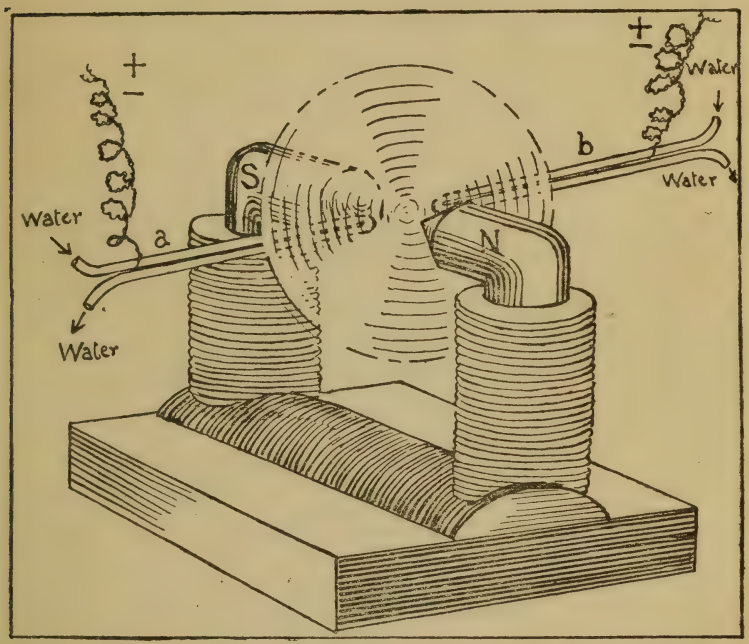

FIG. 41.—Diagram illustrating the Principle of the Birkeland-Eyde Electric Furnace. A powerful alternating current of 3,000 to 5,000 volts is sent through the electrodes *a* and *b*, which consist of copper tubing, through which a rapid stream of water is kept circulating in order to prevent them from fusing in the intense heat of the electric arc generated between them. A powerful electro-magnet placed as seen in the diagram blows out the arc into a rotating disc of flame, which in appearance looks something like a "Catherine Wheel," and consists of burning nitrogen and oxygen.

* For further details of this process, see the *Electrician*, July 13, 1906, p. 494. Also "The World's Work," Vol. X., p. 493, 1907.

carbide it is absorbed and calcium cyanamide is formed, thus :—

$$\underset{\text{Calcium Carbide}}{CaC_2} + \underset{\text{Nitrogen}}{N_2} = \underset{\text{Calcium Cyanamide}}{CaCN_2} + \underset{\text{Carbon.}}{C}$$

This body may be considered as a derivative of ammonia, being the calcium salt of cyanamide :—

$$\underset{\text{Ammonia}}{NH_3} \qquad \underset{\text{Cyanamide}}{NH_2{-}CN} \qquad \underset{\text{Calcium Cyanamide.}}{Ca{=}N{-}CN}$$

When this calcium cyanamide is heated with water under pressure, ammonia is set free according to the equation :—

$$\underset{\text{Calcium Cyanamide}}{CaCN_2} + \underset{\text{Water}}{3H_2O} = \underset{\text{Calcium Carbonate or Chalk}}{CaCO_3} + \underset{\text{Ammonia.}}{2NH_3}$$

Next it was found that this substance when merely spread over the soil was slowly decomposed by the moisture, yielding ammonia and chalk or limestone, and consequently could be used directly as a fertiliser. Indeed, it is stated that the substance is a better fertiliser than ammonium sulphate from gas works, and is quite as good as the best saltpetre. Under the name " Kalkstickstoff " or " Nitrolime " it is now on the markets of the world.

A very interesting property of cyanamide (which can be obtained from calcium cyanamide) is the ease with which it unites with water to form urea—the substance occurring in urine.

$$\underset{\text{Cyanamide}}{CN{-}NH_2} + \underset{\text{Water}}{H_2O} = \underset{\text{Urea.}}{CO(NH_2)_2}$$

Tons of this artificial urea are now made and sold to manufacturers of pharmaceutical preparations. Guanidine, another product of the animal body of which tons are now sold, can also be made from it. Still more wonderful, one of the actual substances—creatine—found in human muscle, and forming the stimulating principle of beef tea, can actually be prepared by uniting sarcosine with cyanamide ! Perhaps we may look forward to the time when many of the actual constituents of our food are directly manufactured from atmospheric nitrogen ! We may still live

to see the creation of as many factories for fixing atmospheric nitrogen as now exist for smelting iron.*

All these facts teach us that the idea with which we started this chapter, namely, that nitrogen is a dead, inert element, is not altogether correct. Inert it certainly is, when compared to most other elements. Yet, like oxygen, the other constituent of our atmosphere, it is continually taking part in a vast cycle of cosmical change by means of which life is maintained upon this earth. According to Arrhenius nitrogen takes part in the vegetative processes nearly a hundred times less rapidly than oxygen, and yet, so vast is the scale on which the fixation of nitrogen is going forward in Nature, no less than one part out of every three million of atmospheric nitrogen is annually removed from the air and conveyed to the soil by the incessant electric discharges which are going on everywhere over land and sea.†

Now the world is hundreds of millions of years old, and if these processes have been going on for all this time the reader will naturally wonder why there still exists any nitrogen in the air. At this rate of fixation a few million years would have sufficed to completely deprive the atmosphere of nitrogen. And yet we find when we examine the crust of the earth that nowhere is there a tendency of nitrogen to accumulate in it. The quantity now fixed in the soil is only just sufficient to supply the wants of the vegetative world. It is clear therefore that there must be some process at work which gives back to the air the nitrogen which yearly is taken from it. And this is so. When animals and plants die and their bodies decay, a considerable proportion of the bound nitrogen in them is set free again by bacterial activity and by oxidation, and finds its way back to its original home, the air. Many of the complex nitrogen

* For further details the reader should see "The Electrochemical Problem of the Fixation of Nitrogen," by Prof. Philippe A. Guye, *Journal of Chemical Industry*, June 30, 1906. Also "Chemical Industry in Relation to Agriculture," by Prof. Franke, *Journal of Chemical Industry*, November 30, 1908. Vol. 27, 1904.

† Arrhenius, "Das Werden der Welten," pp. 130, 131 (1908).

compounds in their bodies, however, pass directly into the soil and thence are absorbed by the roots of plants. Now all animals obtain their nitrogen by devouring plants, and these indirectly or directly obtain their nitrogen from the air. Consequently there is continually going on in Nature an immense and endless circulation of nitrogen. Stupendous quantities are every year withdrawn from the air, and stupendous quantities are returned to it each year. No less than 400 million tons pass in and out of the atmosphere in this way as compared to 40,000 million tons of oxygen!

Every scrap of nitrogen in our bodies once floated in the primeval atmosphere ages before man or beast or plant arose. Every particle of nitrogen in every living thing that creeps upon the earth, in every flower that nestles on the ground, in every tree that grows aloft to heaven, once streamed in the primeval winds of our planet. There is no atom of nitrogen in the air that has not at some time or other in the course of its existence throbbed through the tissues of a living plant or animal, not once but many times.

What a wonderful story, to be sure, could be written of the journeyings of any one of the nitrogen atoms in our own bodies; how it started its existence in the silent black depths of space thousands of millions of years ago; how it then went to form part of the great fiery nebula from which the world condensed; how it then joined the primeval atmosphere of the world, until some mighty flash of lightning in some forgotten storm hundreds of millions of years ago smote it suddenly, and combined it with oxygen; then streaming rain of a thunderstorm washed it down into the soil. How it then entered the rootlet of some plant, and passed into its body, and thence, in the course of endless time, into the bodies of a vast series of creatures who lived and fought and died ages before we came into existence. It has coursed through huge reptiles wallowing in the mud of long-vanished swamps, through extinct plants, through insects, bacteria, and an endless array of other living things, until at last it entered our bodies combined in the food we eat. After a few years or, perhaps, months' sojourn there it will leave us

and again continue its wanderings in the bodies of plants and animals and even in the atmosphere again.

Millions of years after man and all his works have passed like a dream from the earth, the nitrogen atoms which once thrilled in his body will still vibrate in other living forms of life, forms perhaps unknown and undreamt of by him. Truly, when we contemplate Nature closely we find her always in a state of change, stupendous and never-ceasing, and we realise how true and deep were the words of that old-world thinker, Heraclitus, who twenty-five centuries ago declared, "Change is everywhere; everything is and is not. There is no stability. Even in the same river one cannot bathe twice, nor even once."

CHAPTER X

THE ELEMENT CARBON

THE element carbon is, directly or indirectly, the source of nearly all the power used at the present day in the civilised world. The hundreds of thousands of great steam engines ceaselessly working night and day at the present time throughout the whole earth, driving whirling machinery for all the manifold purposes of a great and complex civilisation, derive their gigantic energy from the use of this element as a fuel in the form of coal. The mighty furnaces scattered in countless numbers over every civilised land, whose red tongues of flame waving above their fiery throats light up the sky with a lurid glow in all our great industrial centres, are fed by it. The steel of pen and sword and gun, of engine, girder, rail and bridge, are obtained by its means. Without abundant and cheap supplies of it such valuable and necessary products as copper, iron, tin, lead, and porcelain would scarcely be known except as expensive chemical curiosities. Indeed, our whole present-day civilisation may truly be said to rest upon the use of carbon as a fuel. Withdraw it suddenly from use and all industry would be paralysed. The great factories would close down through lack of power, turning adrift the thousands of men and women employed in them. Engines would cease to run from town to town, and steamers to ply their busy trade on sea and river. Great liners would roll helplessly at anchor in all our seaports, unable to venture out to sea. All the arteries of commerce would be choked and stopped, and ruin would fall upon us all. At first sight it is altogether hard to realise how intimately coal is woven into the life of civilised man ! In our homes carbon provides us with warmth during the cold winter months, and in its absence most of us would probably

have to eat our meat raw as did our forefathers ages ago. In the form of a costly gem, as diamond, carbon gleams on the breast or in the hair of many a whirling ball-room beauty, while as graphite or plumbago it not only provides us with blacklead pencils, but also serves for polishing our boots and for lubricating machinery. Besides being one of the most useful elements, carbon is also one of the most widely distributed. It occurs free in the earth as coal to the extent of over 500 billion tons, while chemically combined it is found in far larger quantities in limestone, chalk, marble, and dolomite, rocks which form so considerable a portion of the surface of our planet. In every 100 tons of marble are nearly twelve tons of coal or carbon, and a slightly smaller quantity exists in the same weight of the other rocks just mentioned. When we reflect that vast mountain ranges, and giant plains, extending for thousands of square miles in area, and for thousands of feet in thickness, are composed of these rocks, we can easily imagine that the amount of carbon thus stored up is stupendous. Once combined, however, we cannot extract the carbon again economically, and, regarded as a possible fuel, this carbon is irretrievably lost.

It is a matter of common knowledge that all living matter, whether of animal or of vegetable origin, when heated strongly in the absence of air, chars and turns into a mass of black coke, thus showing that the element is an essential constituent of all living matter. According to Pettenkofer a man weighing seventy kilos (154 lbs.) contains twelve kilos (26.4 lbs.) of carbon or charcoal; no less than 257 million tons weight of it are stored up in the bodies of men and women living upon the earth at the present time, to say nothing of the far greater quantities occurring in the tissues of trees, plants, and animals. Indeed, coal itself is merely the fossilised carbon of an old-world vegetation which flourished millions of years ago.

Carbon is not confined to this earth alone. It is scattered in inconceivably vast quantities throughout space. Every tiny meteor flying swiftly and silently through space, every grain of cosmic dust, every comet, every planet

whirling round its central sun, nay, every one of the thousands of millions of suns scattered through space contain it. In our own sun it occurs as a gas which condenses in the upper regions of its atmosphere to huge clouds of soot, thousands of miles in diameter and billions of tons in weight, soot not black like the soot from our chimneys, but glowing with an intense heat, and emitting a blinding, dazzling light. These soot clouds surround the sun with a fiery mantle, much as clouds surround our earth, and to them is due much of the fierce brilliance of his surface.

The three distinct forms in which the element carbon occurs, namely: diamond, graphite, and amorphous carbon or charcoal, differ so greatly in properties that we will consider each modification separately.

Chemistry proves beyond all doubt that the exquisitely beautiful thing that we call a diamond* and a piece of ordinary coal or charcoal are composed of the same substance—carbon. The diamond is only carbon which has been fused at an enormous temperature and pressure and then allowed to slowly crystallise. This may be proved in many ways. In the first place we can turn charcoal into diamond, and conversely we can by intense heating turn diamond into charcoal. Again, we can burn both charcoal and diamond in oxygen gas, and in each case we get the same gas, carbon dioxide, produced, and the same weight of it too when we start from equal weights of diamond and charcoal.

Some years ago a ring of speculators ran up the price of coal to fifty shillings a ton, and a picture appeared in *Punch* of a gentleman wearing a coal scarf-pin, which he proudly declared to be "real Wallsend." Many a true word is spoken in jest, for, chemically, a bit of Wallsend is of the

* For further information on this interesting subject the reader should read Sir William Crookes on "Diamonds," *Chemical News*, October 6, 1905, Vol. 92, p. 159. Popular articles have appeared recently in *The Pall Mall Magazine*, Vol. 20, p. 182 (1900), in an article entitled "Gems," by T. C. Hepworth, and in *The English Illustrated Magazine*, Vol. 20 (1899), p. 647. Also "Artificial Diamonds" in *Knowledge*, February, 1908, Vol. 5, p. 26. In Streeter's "Precious Stones" a valuable and interesting account of the subject will be found.

same value as an equal weight of diamond. And yet what an enormous difference exists between them in price! A ton of the best coal may cost twenty shillings, but a ton of good diamonds would be worth about eight million pounds. Yet possibly in future the intrinsic value of the two will more nearly approximate, for diamonds can now be made in the laboratory, as we shall explain immediately, although at present the cost of the operation is greater than the value of the gems produced. Still, who can tell what improvements in the process may be made in the future?

Until recently carbon was considered to be quite involatile and infusible. We now know, however, that it volatilises at the enormous temperature of 3,600° C. *without melting*. The reason of this is that its boiling point under atmospheric pressure lies *below* its melting point; in other words, it boils before it melts. Arsenic is the only other element which does this. Now we have seen in our chapter on water that the greater the pressure we apply to a substance the higher the temperature at which it boils. For example, water boils at 100° C. under atmospheric pressure, but when we increase the pressure on its surface to 196 atmospheres it then boils at 370° C.—a low red heat. In the same way by subjecting carbon to a pressure great enough we could raise its boiling point without affecting its melting point much, and thus we could cause it to boil *above* its melting point. We should thus possess the power of melting carbon and of making diamonds artificially by allowing the molten liquid to slowly cool and crystallise.

Sir William Crookes calculates that at a temperature of about 4,130° C. a pressure of only seventeen atmospheres would liquefy it. There can be no doubt that by subjecting carbon to a very great pressure and an enormously high temperature (lower than 5,500° C.—its critical temperature, —and higher than 4,130° C., its melting point) we should transform it into a clear colourless liquid. On allowing this liquid to cool very slowly the carbon would crystallise out as large transparent sparkling diamonds.

Chemists have not yet succeeded in performing this experiment on a large scale; but a great French chemist—Moissan

—actually succeeded in making microscopical diamonds in this way.*

This was done as follows: Iron when melted dissolves carbon much as water dissolves sugar, and on cooling *at ordinary pressures* liberates it in the form of graphite. Moissan now asked himself the question: Will the carbon separate out as diamond if the pressure be enormously increased? To test this he compressed pure charcoal (made by charring sugar) into a cylinder of soft iron, closed it with a plug of the same metal, packed it with charcoal into a carbon crucible and heated the whole for a few minutes in an electric arc to the enormous temperature of 4,000° C. —a temperature at which iron melts like wax and volatilises in clouds—and plunged the dazzling fiery mass beneath cold water in order to cool it suddenly. We can well imagine that the great experimenter, as he himself confesses, carried out this portion of the experiment with a considerable degree of nervousness, half expecting that a violent explosion would be the result. For molten iron when plunged into water has been known to explode disastrously owing to the generation of gas. Indeed, so hot was the iron that it remained red hot in the boiling water for some minutes. Luckily all went well. The iron cooled and solidified to a hard mass of steel on the outside. Now iron increases in volume when passing from a liquid to a solid state. The sudden cooling solidified the outer layer of iron and enclosed the inner molten mass with a rigid, immensely strong envelope. The inner liquid iron then solidified and expanded in so doing against the rigid enclosing envelope. An enormous internal pressure was thus produced and under stress of this pressure the dissolved carbon separated out as diamonds—not large diamonds such as you see in a jeweller's window, but small, sometimes microscopical ones, worthless as gems, but all the same real diamonds, answering to all the physical and optical tests of the native ones dug out of the soil. These

* The first artificial diamonds were made by Hannay and Hogarth in 1860. Improvements in the process were introduced by Luzi, Moissan, and Majosana, but even at the present time (1909) they have not been manufactured on the large scale.

diamonds, however, are imbedded in a mass of steel and graphite. To separate them the iron was dissolved away in strong acids, and there remained behind a mass of graphite, which, when repeatedly boiled in a mixture of sulphuric acid, nitric acid, and powdered potassium chlorate, gradually oxidised away and left behind the tiny diamond.

The largest artificial diamond yet produced measures less than one millimetre across (say $\frac{1}{32}$ part of an inch) and so is valueless. Still the problem of making larger diamonds is chiefly a matter of power and pressure and length of heating. When we can deal with a thousand pounds of iron as easily as we now deal with four or five ounces, then doubtless large diamonds will be produced. Nature in the depths of the earth operates with gleaming furnaces hotter than any that we can produce, with vast pressures due to hundreds of miles of overlying rock and earth, with time reckoned in thousands of years, and with quantities reckoned in millions of tons ; as a result of these titanic operations she produces magnificent diamonds such as at present we can only admire, not imitate ; but who can say what the future holds in her lap ? Perhaps our children will yet hold in their hands as playthings artificial diamonds such as would now be worth millions and be deemed worthy to glorify crown or sceptre !

We have reason to believe that diamonds are formed in Nature by a process somewhat similar to that followed by Moissan in his experiments. Deep down, buried beneath some six hundred miles of molten or white-hot rock, there lie vast masses of iron and other metals heated to a temperature enormously higher than that which we can produce in our laboratories. Hundreds of miles of rock lying above it have compressed this iron with a force so stupendous as to be almost inconceivable to us, while at the same time it is impregnated with carbon, which under such conditions is freely miscible in it. In consequence of slow upheaval going on for ages, and sometimes on account of some great volcanic disturbance, these low-lying carbonaceous layers are sometimes forced nearer the surface, and then slowly cool during hundreds or thousands of years. In consequence of this the dissolved carbon separates out as tiny fluid globules,

which run together and form still larger globules. Finally as the magma cools down still more, the carbon crystallises out as diamonds. The general appearance of many of these precious stones favours this view of their origin. Some diamonds look like drops of liquid which have separated in a pasty condition and have then crystallised on cooling. Others have but little appearance of crystallisation, but have a round form, similar to that assumed by a liquid when kept in the midst of another with which it will not mix. If many of these drops of liquid carbon are maintained for a sufficient time above their melting points they coalesce with adjacent drops, and on slow cooling separate out in the form of large perfect crystals. Diamond crystals are generally perfect on all sides. They show no irregular side or face by which they were attached to a support—another proof that they have crystallised out from a dense liquid. The extreme internal tension known to exist in diamonds which causes many to burst or explode when brought to the surface for the first time indicates that they have been formed under conditions of great pressure deep down in the earth, a pressure from which they relieve themselves when they suddenly expand outwards and fly to pieces. Most artificial diamonds and many natural ones are but fragments or splinters of perfect crystals, which have burst in this way.

Undoubtedly the diamonds now found near the surface of the earth have been brought up from the earth's molten interior by the volcanic convulsions of former ages. At any rate in South Africa the diamonds are actually found in old volcanic ducts filled with a peculiar blue earth which, like vast "pipes" or "chimneys," rise from unknown depths and burst through the surrounding shales. The old volcanoes, of which these were the throats, have, however, been swept away ages ago by wind and rain from off the earth, and their materials disseminated over the surrounding districts. All that remains of them are these pipes plunging into the earth. The diamonds that we find so often in the beds of streams, and in alluvial soils, occur in the debris of these washed away volcanoes. The diamond is chemically

FIG. 42.—De Beers Mine, Kimberley—Open Workings.

(Photographed by Mr. J. E. Middlebrook, Kimberley.)

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almost unalterable at ordinary temperatures and endures for ages. Long after the rock in which they were originally imbedded has been corroded away by wind, rain, and carbonic acid, the diamond remains unchanged. The vast diamond fields of old India were of this alluvial nature and are now exhausted ; but somewhere under the soil, perhaps buried by the mud and ash of millions of years, there still must exist old diamond pipes coming out from the depths below. No man has found them yet, and perhaps we never shall ; but deep down the diamonds are still there, and may some day be discovered by a lucky adventurer.

In South Africa, however, these pipes have been discovered, and the miners are steadily digging their way down them towards the interior of the earth. Already they have penetrated them for thousands of feet, and still there is no diminution or slackening in the diamond supply. How far down these mines will ultimately extend we cannot say. The heat of the earth will prevent them from going deeper than a few miles, but there is no reason to doubt that the diamond rich pipes may go down for scores of miles into white hot regions below, and join immense reservoirs of diamond-rich rock.

The discovery of these diamond fields is itself a romance. It appears that in 1867 a child of a Dutch farmer, Jacobs by name, found a pretty pebble in a stream in the neighbourhood of the farm, near Hopetown. The brightness of the stone attracted the keen eye of the mother, though she regarded it simply as a curious pebble, and gave it little more than a passing glance ; but in the solitude of the bleak countryside every little incident furnishes food for conversation, and so it happened that some time afterwards when a neighbouring boer, named Schalk van Niekerk, visited the farm, Mrs. Jacobs told him about the bright transparent stone. Being a thoughtful intelligent man, interested in such things, he asked to see it ; yet so carelessly had the stone been kept that when wanted it was nowhere to be seen. After some searching it was at last found lying on the ground just outside the house, where it had happened to fall when the child had used it last as a plaything. Van Niekerk

had never seen a stone like this before and offered to buy it. Mrs. Jacobs laughed at the notion of selling so common a pebble, and at once gave it to the farmer. The latter put it in his pocket and some time later showed it to a trader, O'Reilly by name, who was going south from a hunting and trading expedition, and asked him to try to ascertain its nature from any trustworthy mineralogist he might meet. It was taken to Colesburg and thence dispatched by post to Dr. Atherstone, of Grahamstown, who was known to be an excellent mineralogist. Of so little value was the stone thought to be that it was sent unregistered through the post gummed up in an envelope as an ordinary letter. Dr. Atherstone after a careful examination pronounced it to be a diamond. And so it happened that the plaything of a child was sold later for £500 !

Of course this discovery caused a great sensation, and every one began searching their back gardens for diamonds, with the result that these stones were found scattered far and wide over the whole countryside.

Near Colesburg a Dutch farmer named Tan Wyk was surprised to find diamonds actually imbedded in the walls of his house, which had been built of mud from a neighbouring pond. This led to the ground round about being examined, which was also found to contain diamonds. Soon a rush of men occurred to the place, and it was found that on continuing to dig lower and lower diamonds were still brought to light ; nor did they cease when the rock bed was reached. Such was the origin of the famous Kimberley Diamond Mine, which from that day to this has never ceased working, and which at the present time employs nearly twelve thousand coloured men and three thousand white men. Over ten tons weight of diamonds have been found, representing a value of about eighty million pounds. So long ago as 1899 the company were exporting over two million pounds worth of diamonds, and since that date the quantities have increased. Indeed, experts say that the mines are inexhaustible. The work goes on night and day, Sundays included, without intermission. Two thousand men are employed below for eight hours at a time. The remainder live on the surface,

and while awaiting their turn are enclosed in compounds, vast squares walled in and surrounded on the inside with sheds, where the negroes sleep on the bare ground. "They are entirely cut off from the outer world for three months," says Mr. Sillard,* "then, any one who wishes to leave his work (except the convicts) is kept in a room by himself for a week, where all his clothing is taken from him, and he is compelled to take medicine of no delicate nature, lest he may have swallowed some of the coveted gems. That such precautions are necessary can be gathered from the fact that some time ago one fellow had a sore leg, and had it well bandaged just as he was leaving. The defective limb was examined, and in a self-inflicted wound were found nine small diamonds, worth about sixty pounds."

Sometimes visitors are allowed down the mines, and it is a sight never to be forgotten. "They are," says Mr. Sillard, "first provided with a full rig-out of waterproof clothing, boots, and other apparel. They are then brought to the hauling gear, and put into a cage-like lift, or elevator, which descends at a very rapid rate through intense darkness for a distance of fifteen hundred feet or more. When the visitors are 'landed' they find themselves in a vast chamber brilliantly illuminated with electric lights, and a thousand coloured men at the searching work. They are next conducted through a tunnel half a mile long to where the diamond bearing material is being dug up. Along this tunnel are two lines of rails with many hundreds of trolleys; one set of rails conveying full, and the other empty trolleys, and all propelled by the same endless wire cable. The 'blue ground' which bears the diamonds is brought to the surface in astonishing quantities. It is spread on floors, about five hundred acres in extent, for several months. Here it disintegrates to dust and then the precious gems are collected. All round these floors are placed guards at short distances, who keep watch day and night, and on an eminence is a sort of observatory furnished with powerful telescopes, searchlights, etc., so that even on the darkest night any part of the floors, or any of the guards or workmen, can

* *The English Illustrated Magazine*, Vol. 20, March, 1899, p. 651.

be inspected instantly. It may be gathered from this short sketch that there are few places of more interest on our planet than a Kimberley diamond mine."

Next time my reader sees a diamond gleaming in a jeweller's window in a busy city street, or glittering on a lady's attire amidst the light and music of a ballroom, let him recollect for a moment its strange story; how it was conceived in the depths of the earth in an ocean of liquid fire; how it slowly grew and took form during countless ages of slow cooling in mighty subterranean furnaces; how it was suddenly brought to the surface during some titanic convulsion of the earth's crust, when, amidst vast thunderings, the earth split open and torrents of white-hot molten rock came pouring out from the throat of some old-world long-vanished volcano, millions upon millions of years ago, bearing with it our diamond; how it lay buried in rock in utter silence and darkness for age after age, while successive races of plants, animals, and men, came into existence, rose to power, slowly declined and passed away; how then at last its long rest was broken, the pick axe of man was heard, daylight flashed in upon it, and it was plucked from its age-long hiding-place, and sent to circulate from hand to hand in the world of men and women. Whence came the carbon of the diamond? Probably from a living plant. Yes, possibly every diamond in the world at some remote epoch, millions upon millions of years ago, formed part of a living plant! First as carbon dioxide gas in the air, then as wood in a tree, then as coal, then, deeper in the earth as graphite, and finally, after undergoing the purification of the fierce central fires, as a glittering gem—this is the strange life-story of the diamond!

The diamond is the hardest of all known substances. So hard is it in comparison to glass that a suitable diamond splinter will plane curls off a glass plate much as a carpenter's tool planes shavings off a wooden board! Although so hard it is very brittle. A fall may smash it like a piece of glass, while a blow from a hammer will shiver it into dust.

When first found diamonds are rough, unattractive pebbles, and it is only after they have been cut and polished that they become the beautiful gems we see set in rings and tiaras.

FIG. 43.—Searching Tables, De Beers Diamond Mines, Kimberley.

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We have already alluded to the fact that many diamonds are in a state of intense internal stress or strain. Some of them contain millions of minute cavities filled with gas at enormous pressure. Liquid carbon dioxide is often contained in them, and the strain is set up in the stone by the effort of the gas to escape. This is the reason why diamonds so often explode soon after reaching the surface of the earth. Some have been known to burst in the pockets of the miners or when held in the warm hand. The loss is often very considerable, as large stones are more liable to fly to pieces than small ones.

It is said that dishonest dealers often allow responsible clients to handle or carry in their warm pockets large crystals fresh from the mines. To insure against explosion when transmitting diamonds long distances many dealers embed them in raw potatoes. A very fine piece of artificial diamond, carefully mounted by Sir William Crookes on a microscopical slide, exploded during the night and covered its slide with fragments. This phenomenon appears to be the reason why in Nature so many diamonds appear as splinters broken off from larger crystals. The same thing applies to the artificial diamonds. It is only very seldom that a perfect crystal is found.

Since the diamond is only crystallised coal it is but natural that it will burn. Indeed, it would be possible to have under certain conditions a diamond fire instead of a coal one, although, I am afraid, that this would be an expensive luxury even for a millionaire. He would have to pay about eight million pounds for every ton of diamonds he burnt.

If a diamond be heated white hot and plunged into a jar of oxygen gas it will burn with a dazzling white light, just like a bit of coal or charcoal would under the same circumstances, leaving behind a minute trace of ash and forming the invisible gas carbon dioxide :

$$\underset{\text{Diamond}}{C} + \underset{\text{Oxygen}}{O_2} = \underset{\text{Carbon Dioxide.}}{CO_2}$$

It is almost unnecessary to say that this is the gas yielded by every fire and gas burner, and by the combustion of

our own bodies. These latter, in the combustion that attends their very living, evolve carbon dioxide by the lungs, so "that the old fable of the maiden from whose lips fell diamonds may have a really scientific basis after all."

It is related that owing to this cause Francis I. of Austria in 1751 suffered a great loss. The story runs that one morning he received an anonymous letter from an alchemist containing full directions for melting diamonds. The king at once placed together in a crucible some six thousand guldens worth of small diamonds and rubies, and heated them strongly in a fire for a day and a night, hoping by this means to melt together the stones and obtain from them a large diamond of great value. It was a lucky thing for the alchemist that he had concealed his identity, for next day when the king ordered the crucible to be removed from the fire and opened, he found that the diamonds had all disappeared while the rubies were left unaltered! They had simply burnt away like bits of coal.

In the year 1771 a magnificent diamond was burnt in the laboratory of the chemist Macquer at Paris, and it was this experiment which ultimately led to the discovery of the true nature of the diamond. Streeter thus relates the story:

"The fact was undoubted; the diamond had disappeared; but whither? Had it volatilised? Had it burnt? Had it exploded? No one could say. Upon this there stepped forward a celebrated jeweller of Paris, by name Le Blanc, who asserted the indestructibility of the diamond in the furnace, stating that he had often placed diamonds in an intense fire to purify them from certain blemishes, and that they had never suffered the smallest injury. The chemists, D'Arcet and Rouelle, then demanded of him that he should make the experiment on the spot in their presence. He took some diamonds, enclosed them in a mass of coal and lime in a crucible, and submitted them to the action of the fire. He had no doubt that he should find them safe. But, alas! he had sacrificed his diamonds; for at the end of three hours, on looking into the crucible, they had utterly disappeared. The scientific men, however, did not long enjoy their triumph. Another jeweller, Maillard, in the presence of the celebrated Lavoisier, took three diamonds and closely packed them in powdered charcoal in an earthen pipe-bowl, in a strong fire; and when the pot was taken out there lay the diamonds in the powdered charcoal untouched. It was, however, gradually discovered that it was only by entirely shutting off the

air and therefore the oxygen, with which carbon combines, that the diamonds were preserved from burning; whereas, by the simple admission of air of which oxygen is a constituent part, diamonds burn just the same as common coal. This fact Lavoisier proved in 1776; and Davy subsequently proved that the diamond contains no hydrogen."*

A diamond if heated to a white heat in the electric arc swells up, turns black, and is converted into a valueless mass of graphite.

The diamond is one of the most valuable gems (rubies, however, are worth weight for weight far more), those which are colourless being especially prized. One of the most beautiful of this kind is the Pitt or Regent Diamond. It originally weighed 410 carats (1 carat=3.17 grains or 0.2504 grams), but after being cut it only weighed 136.25 carats. This gem was found by a poor slave in India at Purteal, who concealed it in a gash made for its reception in the calf of his leg. One dark night he fled away, and wandered through the land until he came to Madras. There, walking among the shipping, he saw an English skipper, and confided to him his secret. This scoundrel said that he knew of a purchaser, and lured the slave on board his ship. Here he treacherously murdered him, taking the diamond and flinging his body overboard. Some days afterwards he offered it to a dealer named Jamchand, and obtained £1,000 for it. This he ran through by all manner of excesses, and then, being haunted by his crime, he hanged himself. Jamchand sold it in 1710 to Thomas Pitt (grandfather of the great Earl of Chatham), at that time Governor of Madras, for £10,000; but the risk of keeping such a valuable gem was too much for his nerves; he was unable to sleep at night for fear of thieves; and so it came about that in 1717 he sold it to the Duke of Orleans, Regent of France, for £130,000. When that mighty catastrophe, the French Revolution, plunged all France into bloodshed and disorder, some robbers during the night got into the vast chambers of the Treasury by climbing in through a window and stole it. Some days

* Streeter's "Precious Stones," quoted by kind permission of the author.

afterwards it was discovered in a ditch, and thus recovered. Among other great diamonds, many of which have had an even more romantic history than the Regent, may be mentioned the Koh-i-noor, now a British Crown Diamond. This stone is of Indian origin, and is stated to be 4,000 years old. Its authentic history begins about 56 B.C. One stands amazed to think of the long line, fading away into antiquity, of kings, princes, and queens, who have seen and handled this stone. The numerous tragedies which have been associated with it, and its strange wanderings, make up a romance as strange as any story in fiction. Its history, however, is too long to be related here. Among other famous diamonds may be mentioned the Orloff, The Star of the South, The Mattan, and the Hope.

The Hope diamond is of a magnificent blue colour, and it has a superstition attached to it that it brings misfortune and disaster to all who possess it. Within the last few years it has been in Constantinople, and if it be true that it was in the possession of Abdul Hamid, that his favourite was wearing it when she was shot, and that nearly every one concerned with it met speedy death or disaster, it would only be in accordance with the gloomy history of the gem. For this is a list of the authenticated tragedies :

Andreas Tavornia, the diamond merchant who sold it to Louis XIV, after bringing it home from the East.	Ruined in old age, and died of fever on a journey to the East to recoup his fortunes.
Madame de Montespan, who wore it.	Supplanted by Madame de Maintenon.
Nicolas Fouquet, who borrowed it.	Disgraced and imprisoned.
Marie Antoinette, who wore it.	Beheaded.
Princesse de Lamballe, who wore it.	Torn to pieces by Paris mob.
Louis XVI, who owned it.	Beheaded.

In the troubles of the French revolution the stone was stolen, but mysteriously came to light again some years later, and in 1830 passed into the hands of Mr. Hope. Quite recently it has been sold. " It looks as if people were really

getting afraid of the Hope Diamond," says *The Sunday Observer*, in June, 1909, "on Thursday it fetched only £16,000, though it changed hands a few years ago for £28,000. So long ago as 1830 Mr. Hope gave £18,000 for it, and the recent increase of millionaires should have sent up the price enormously. Most significant of all is the fact that even in

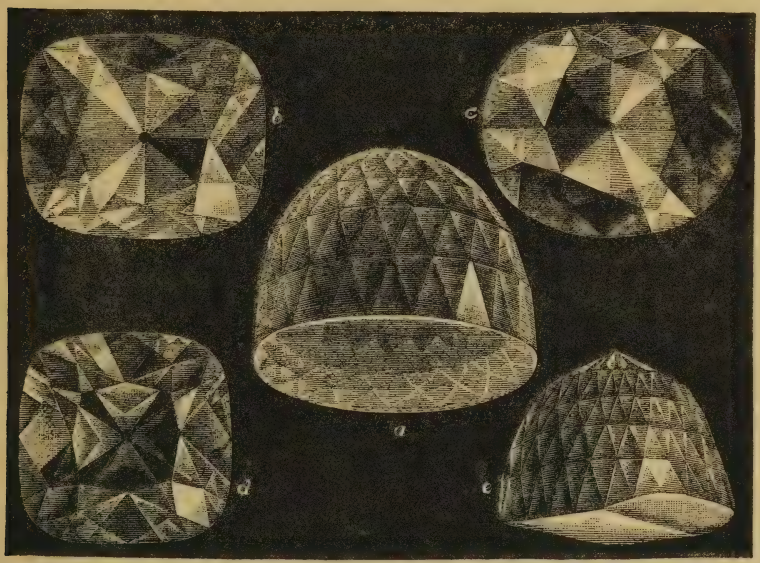


FIG. 44.—Some Historic Diamonds. *a*, Great Mogul; *b*, Star of the South; *c*, Koh-i-noor; *d*, Regent; *e*, Orloff—all actual size.

[Illustration from "Chambers's Encyclopædia," article "Diamonds," reproduced with permission of the publishers.]

America, whither it went in 1901 after Lord Francis Hope was permitted to dispose of it, no purchaser could be found."

The largest diamond ever discovered either in ancient or modern times is the Cullinan Diamond, of 3,025 carats, found at Pretoria in 1905. Mr. F. Wells, the manager of the Premier Diamond Mine, was making a tour of inspection between four and five o'clock in the afternoon. Suddenly he saw the rays of the setting sun reflected from a bright object high up in the mine face. He climbed the sloping

bank and saw the projecting edge of an enormous diamond. With his pocket knife, which he broke in his feverish efforts to dislodge the gem, he succeeded in digging it out. The diamond, when being shipped to England, was insured for £500,000, and has since then been cut into a number of smaller stones, and now forms part of the Crown Jewels of the British Throne.

We now come to the second modification of carbon. This is graphite. We are all more or less familiar with it. It is the shiny, soft substance used for black lead pencils, for polishing boots and fire-grates, for lubricating revolving machinery, and for many other purposes.

Graphite has a metallic lustre, and so well does it conduct electricity that it is actually used for making moulds on which it is desired to deposit metals in electrotyping. Metals are deposited on it as on another metal.

The substance has been called "blacklead" for centuries, because it looks exactly like a dull sort of lead, and like it marks paper. Blacklead pencils, however, are no modern invention. For in the year 1565 appeared a book by Conrad Gessner, entitled "De Rerum Fossilium Figures," in which is a picture and description of one of these pencils. It is not known how long these articles have been used, but certainly they are centuries old.

Graphite is one of the most infusible and involatile substances that we possess, and consequently is used for making crucibles and vessels capable of withstanding the terrific temperatures of the electric furnace, temperatures at which all other substances melt like wax and even boil. Such vessels have recently become very important on this account.

We have seen when discussing diamonds that molten iron (and other metals as well) dissolves carbon, which crystallises out on cooling as graphite; but this is not how it is formed in Nature. It occurs in mines in different parts of the world (Germany, Bohemia, United States, Siberia, Ceylon), and has undoubtedly been produced from coal. We may picture the process as follows: The earth's surface is in eternal motion. Hills rise out of the sea in the course of ages, while continents sink slowly below it. We know, for example,

that the whole of central Europe was once a huge inland sea. England has been under water two or three times during past ages. Now, in consequence of these great earth movements, it sometimes happens that beds of coal sink to such great depths as to become highly heated by the intense internal heat of the earth. This heat, combined with the enormous pressure exerted by miles upon miles of rocks above, causes the coal to become graphite. In subsequent ages the crust may be uplifted again and the graphite brought to within mining distances of the surface. Mendeléef has observed this gradual transformation of coal into graphite as the strata sinks in the valley of Aosta near Mount Blanc.*

Graphite is now manufactured in large quantities by electrical processes. Girard's and Street's method is to send a powerful electric current through compressed charcoal or coal dust. An immensely high temperature is thus produced, and the carbon passes into graphite.

In Acheson's process, which is worked in his great manufactory at the Niagara Falls, a mixture of sand and coal is heated in a special form of electric furnace. Carbon silicide or carborundum is formed at first, but under the vast heat the silicon volatilises away and leaves behind pure graphite, which is much better than that which comes from the mines.†

Graphite is produced also as a by-product when high-boiling hydrocarbons are distilled out of iron retorts, or when acetylene gas is sent through red hot tubes.

Amorphous carbon or charcoal is the third modification of carbon, a variety which differs from diamond and graphite, in possessing no distinct crystalline structure. Many varieties exist, such as lampblack, gas carbon, and charcoal. Lampblack or soot is manufactured by suspending metallic cylinders over oil lamps, the soot then condenses on them, and can be purified by heating in a stream of chlorine gas, which removes every trace of hydrogen.

Compressed acetylene gas slowly decomposes, giving an extraordinary fine form of soot. The substance is used for

* Mendeleef : " Principles of Chemistry," Vol. 1, p. 340 (1891 Ed.).

† A full description is given in *Cassier's Magazine*, Vol. 26 (1904), p. 24. " Some Electric Furnace Processes," by J. Wright.

making "Chinese ink," "printers' ink," and certain black lacquers and varnishes.

Gas carbon, obtained by distilling coal in making coal gas, is much used in electric lighting.

Charcoal is obtained by heating sugar, wood, or bones in closed vessels. It has many valuable properties, being among other things an excellent fuel, burning without smoke or flame. Charcoal powder, especially that prepared by heating bones or blood (animal charcoal), has great disinfecting and decolourising properties. The reason of this is that it possesses the power of absorbing various putrefactive gases, thus bringing them into contact with oxygen gas, which is also absorbed within its pores. Oxidation proceeds, and the gases are converted into harmless compounds. This is one of the reasons why the interiors of watercasks on ships are often charred and blackened, the layer of charcoal keeping the water pure during the long sea voyage.

A piece of formless black charcoal may at first sight appear to have nothing particularly interesting about it. Yet how deceptive are first appearances! for this, if magnified a few hundred thousand times, would be seen to have a structure so complex as to be beyond all power of description. The substance possesses a froth-like structure, and is filled with numberless caverns, tunnels, rooms, and galleries, lying thick one over the other in endless confusion. Within them prevails a very great attractive force, and in consequence of this they are filled with closely packed molecules of gases which have been sucked into the dark pores and passages and there stored up. Thus a piece of freshly made charcoal will absorb no less than 170 times its volume of ammonia gas at ordinary temperatures and pressures. A similar process of absorption takes place with other gases as well. The gases thus stored up in these chambers are so strongly compressed as to be almost liquid! At low temperatures this power charcoal has of taking up gases is enormously increased. An almost perfect vacuum may be made by absorbing the gas in a closed vessel by means of charcoal cooled to the temperature of liquid air. For the same reason charcoal will precipitate a great many substances from solution and

absorb them into its pores. Thus, if a quantity of red wine—say claret or port—be shaken and gently warmed with a quantity of freshly made bone charcoal, then, on filtering, the liquid which comes through is found to be quite colourless. This property of charcoal is made use of on the large scale in many industries for removing objectionable colouring matter from syrups, sugars, and other preparations.

Coal is simply fossilised carbon, the charred remains of a bygone vegetation. It is found in the older geological formations, reaching right up to the Tertiary Period. Coal occurs in every part of the world, even in regions now buried perpetually under thousands of feet of ice and snow—a fact which shows that the desolate polar regions once possessed a tropical climate. Vast masses of it occur buried in China, North America, England, and Germany. The total amount has been estimated as over 500 billion tons.

Coal is largely composed of the giant club-mosses of the past—mosses so huge that their stems were three or more feet in diameter and fifty feet in length! Most of the present club-mosses are only a few inches long. We also find in coal remains of immense ferns, with stems sometimes six feet in diameter and seventy feet in length. Here in vast swamps, crowded together in a way scarce known upon the earth at the present day, grew and flourished these giant masses of vegetation. The seas in those old days were fuller than at present, for their waters had not sunk into the earth to the same extent that they now have. They flooded the low-lying land and formed shallow swamps, extending over hundreds of thousands of square miles. Moreover, their waters were, perhaps, still warmed by the internal heat of the earth. The steaming seas warmed the air, filling it with mists and vapours, and making it tropical over every clime. Moreover, the atmosphere was still far richer in carbon dioxide than at present, and this alone raised the general atmospheric temperature some degrees, and provided the vegetation with abundant nourishment.

All these circumstances made vegetation grow in a way that is beyond our conception. In the swamps tree after tree arose, springing up rapidly, then decaying and dying,

and choking up the ground with their seeds and fallen stems. As they decayed they fell one over the other and thus built up a vast undergrowth of decaying wood and vegetables. On this in turn grew fresh plants, only to decay and fall, until masses of evil-smelling, decaying vegetation, hundreds, perhaps thousands of feet thick were built up. These masses, sinking in time below the sea, became covered over with sediment and sand thousands of feet thick, and after countless ages of slow change became converted into the coal of to-day. To explain this we may say that when we heat wood or vegetable matter strongly in the absence of air at ordinary temperatures it blackens, turning into carbon, eliminating its hydrogen and oxygen. The same change will take place at ordinary temperatures, heat merely accelerating a process that will complete itself entirely at ordinary temperatures in the course of many thousands of years. A chemical action which requires hundreds of years at 0° C. to complete itself will often require only days at 100° C. and seconds at a red heat. Heat is a great accelerator of all chemical change; the gases which escape into coal mines are set free owing to these slow changes progressing within the coal itself.

The coal, therefore, which we now burn in our grates is merely the fossilised carbon from these ancient gloomy forests which flourished and vanished ages before man trod the earth. Strange indeed they must have looked, full of huge ferns and mosses and hanging creepers clustering together in a tangled mass, with the sun's rays streaming in from above, vainly endeavouring to light up the darkness of the moist, decaying, evil-smelling ground below.

Such forests, where coal is even now forming, may be seen in some parts of the world. In the valley of the Mississippi may be seen vast masses of vegetation, forests standing in swamps, above a mass of rotting timber, extending to the depth of several hundred feet, just such a mass as once existed in our coal fields when they were being formed.

"If the reader wishes to picture to himself the scenery of what is now central England, during the period when our coal was being laid down, he has only, I believe, to transport himself in fancy to any

FIG. 45.—An Ancient Coal Forest.

The coal we burn in our grates is merely the fossilised remains of these ancient gloomy forests, which flourished and vanished ages before man trod the earth.

(Illustration from "The Subterranean World," by George Hartwig. Longmans, Green and Co. 1871.)

Face page 226.

great alluvial delta, in a moist and warm climate, favourable to the growth of vegetation. He has only to conceive wooded marshes, at the mouth of great rivers, slowly sinking below the sea; the forests in them killed by the water, and then covered up by layers of sand, brought down from inland, till that new layer became dry land, to carry a fresh crop of vegetation. He has thus all that he needs to explain how coal measures are formed. I myself saw once a scene of that kind, which I should be sorry to forget; for there was, as I conceived, coal, making or getting ready to be made before my eyes: a sheet of swamp sinking slowly into the sea; for there stood trees, still rooted below high-water mark, and killed by the waves; while inland huge trees stood dying, or dead, from the water at their roots. But what a scene—a labyrinth of narrow creeks, so narrow that a canoe could not pass up, haunted with alligators and boa-constrictors, parrots and white herons, amid an inextricable confusion of vegetable mud, roots of the alder-like mangroves, and tangled creepers hanging from tree to tree; and over-head huge fan-palms, delighting in the moisture, mingled with still huger broad-leaved trees in every stage of decay. The drowned vegetable soil of ages beneath me; above my head, for a hundred feet, a mass of stems and boughs, and leaves and flowers, compared to which the richest hothouse in England was poor and small. But if the sinking process which was going on continued a few hundred years, all that huge mass of wood and leaf would be sunk beneath the swamp, and covered up in mud washed from the mountains, and sand driven in from the seas; to form a bed many feet thick, of what would be first peat, then lignite, and last, it may be, coal, with the stems of killed trees standing up out of it into the new mud and sand-beds above it, just as the Sigillariae and other stems stand up in the coal beds both of Great Britain and of Nova Scotia; while over it a fresh forest would grow up to suffer the same fate—if the sinking process went on—as that which had preceded it."*

Now let us relate a wonderful thing. This carbon in the plants was obtained by them from the carbon dioxide (CO_2) in the air by the agency of sunlight. The plants absorbed the gas, the light decomposed it to carbon and oxygen, the oxygen was given up to the air while the carbon remained stored up in the tissues of the plant, to be finally turned into coal, dug out of the earth by man after long ages, and burnt again in his fires to carbon dioxide—its original form of combination. Thus the sunlight which lit up this ancient Palæozoic world separated out the carbon;

* "Kingsley's Essays," Vol. 19, p. 105 (Macmillan, 1880, quoted by kind permission of the publishers).

and the energy which the sun once thus expended is now given back to us again as heat and light in our coal fires. So that we may in a sense regard the heat from the burning coal as part of the heat and light radiated from the sun millions and millions of years ago! Moreover, the oxygen in the air, which is roughly chemically equivalent in quantity to the amount of carbon found as coal, has probably all been for the most part derived from carbon dioxide in this way. It was once combined in the air with the coal we burn.

My reader will now, I am sure, look upon a piece of ordinary coal with increased interest. For it is a very wonderful thing, with a very wonderful history behind it, a history fraught with the mightiest cosmical effects, and most intimately bound up with the life of man and beast. Each piece of coal is old, far older than any of the hills around us. It has endured while untold races of men and animals have gone by and faded; it was there when vast reptiles roamed in gloomy swamps and man was not as yet; in comparison to it man is a thing of yesterday.

Most elements have strong chemical attractions for some elements and very weak attractions for others. Thus, oxygen has a very strong attraction for hydrogen but hardly any at all for gold. Carbon, too, conforms to this rule, but with this difference: while other elements exert their strongest attractions on elements *different* from themselves, carbon has the remarkable peculiarity *of exerting its greatest attraction on its own atoms.** They combine together with extraordinary power.

This fact explains almost all the remarkable peculiarities of carbon. It explains, for example, its extraordinary involatility. The highest temperature yet produced upon the earth barely suffices to volatilise it; but on the sun, that stupendous mass of white-hot rushing gas, the heat is so incredibly great that even carbon boils and forms vast whirling masses of vapour surmounted by dazzling white-hot clouds of condensed soot—clouds which give the sun much of its brilliance.

* Full evidence in support of this view is given in the author's work, "Researches on the Affinities of the Elements."

It explains, too, the wonderful chemical inertness of carbon at ordinary temperatures. For before a substance can take part in a chemical change its molecules must, partially at any rate, split up into their component atoms. But obviously molecules whose atoms are very strongly attracted together will not split up so, and consequently are indifferent towards other atoms. This is the reason why carbon is *at ordinary temperatures* one of the most chemically inactive substances known. It will not combine with any other element, nor will it dissolve even in the strongest acids.*

The unalterability of charcoal under the action of atmospheric influences which produce changes in the majority of stony and metallic substances is often made use of in practice. For example, charcoal is frequently strewn in boundary ditches. The surface of wood is often charred to render it durable in marshy soil where the wood itself would soon rot. In chemical works the chambers through which acid vapours pass are filled with coke, because at ordinary temperatures it resists the action of the most energetic acids. Indian ink and printers' ink will last for centuries without fading. They owe their stability to the unalterability of carbon under atmospheric influences, being composed of fine carbon particles. The manuscripts of Herculaneum were written with carbonaceous ink, yet after 1800 years they are unchanged! But this is only at ordinary temperatures. At a red or white heat carbon awakes from its deathlike sleep and becomes one of the most chemically active elements known, burning in oxygen, reducing metals from their ores, and at the still higher temperatures of the electric furnace combining with almost all the metals to form carbides.

This intense self-attraction of carbon explains, too, the astonishing complexity of its compounds. For the carbon atoms combine together to form frameworks of vast complexity. By the attachment of atoms of hydrogen, oxygen,

* Certain bacteria are stated to have the power of oxidising carbon at ordinary temperatures. If this is really so it furnishes us with another example of how enormously the power of living matter to carry out chemical actions transcends that of the chemist working in his laboratory.

sulphur, nitrogen, and phosphorus to these frameworks we get that tremendous array of complex organic substances found in animal and in vegetable matter, as well as in the numberless artificial dyes and drugs now manufactured. What a wonderful glimpse we obtain into the mystery of living matter when we study the complex bodies produced as the product of its incessant change! a single molecule of starch—the constituent of many plant cells—has according to Brown and Morris the formula C_{1200} H_{2000} O_{1000}, being composed of 4,200 atoms all linked together! Cellulose—the hard skeleton of wood, cotton, and plants generally—has an even more complex molecule. Its empirical formula may be represented by the little expression C_6 H_{10} O_5, but its actual molecule may be fully a thousand times greater, viz.: C_{6000} H_{10000} O_{5000}. It seems hopeless to attempt to make such a substance. Every one knows the infinite number of configurations in which it is possible to arrange 21,000 articles. In the words of a recent writer,* "Given that a certain unseen house consists of 6,000 pieces of wood, 10,000 pieces of stone, and 5,000 pieces of iron, build its duplicate blindfold; this is a problem somewhat more or less difficult than the synthesis of cellulose. Yet every plant performs this feat with unerring certainty when it builds up its cellulose skeleton—how no one has the remotest idea." Equally complex are certain sugars, albumens, and other

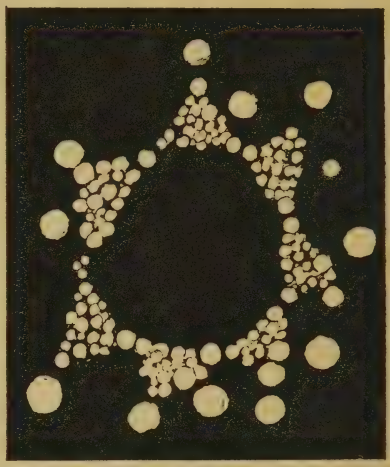
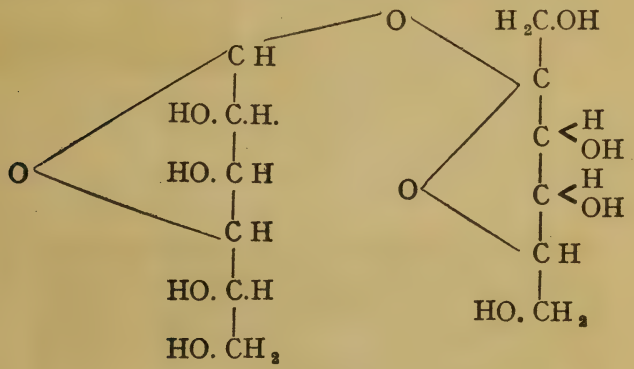


FIG. 46.—The Benzene Ring. A ring of Six Carbon Atoms (the tetrahedrons) with other atoms attached. Many of the compounds contained in Coal Tar consist of molecules containing such rings.

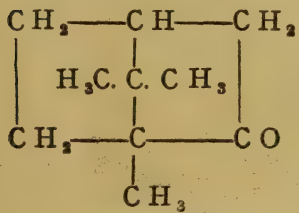
* "The Chemistry of Commerce," by Prof. Duncan (1907).

bodies existing in a state of ceaseless change in living plants and animals. Their molecules consist sometimes of thousands and thousands of carbon atoms linked together in long strings. The sugars are long chains of carbon atoms to which are united hydrogen and oxygen atoms. One of the best known sugars is cane sugar, $C_{12}H_{22}O_{11}$; whose molecule is believed to be built up in this way:

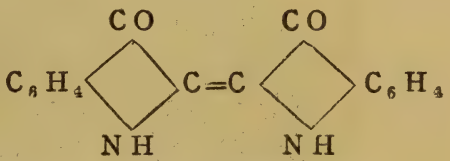


Cane Sugar.

The dashes represent how the atoms are linked up in the molecule. Of course many of the sugars occurring in the animal and vegetable body are far more complex than this, while at the same time still simpler sugars exist. Among the more simple frameworks are those occurring in camphor, indigo, and allied bodies:



Camphor.



Indigo.

Similar frameworks occur in a large number of dyes, a few of which are pictured in the illustration.

When we reflect that in these innumerable numbers of vastly complex molecules the atoms are not at rest, but are in eternal motion like the planets round the sun, each performing its own little evolutions in the molecule with enormous rapidity and great regularity—as the wonderful absorption spectra of such bodies prove—we seem to obtain a dim glimpse of the wonders that we would see in organic nature if we only possessed the means to render visible the molecules. In this case no doubt a new and undreamt of universe

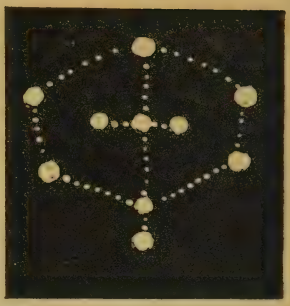


FIG. 47. — Framework of Carbon Atoms occurring in Camphor.

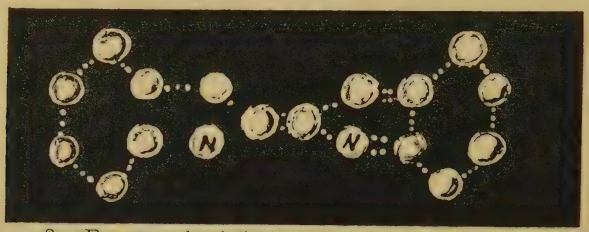


FIG. 48.—Framework of Carbon Atoms occurring in Indigo.

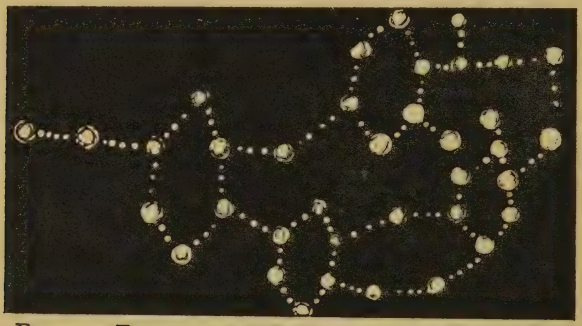


FIG. 49.—Framework of Carbon Atoms occurring in a Complex Organic Dye.

would burst upon our view, a universe rivalling in complexity the stellar universe above. Think of it—each carbon

atom consists of 20,000 smaller particles, each oxygen atom of 30,000, while a single complex molecule like that of cellulose may well contain over 300 million electrons —as many particles as there exist visible stars in the universe around us! Such a molecule is in itself a universe, and yet each stick and each leaf contain countless billions of them. The mind reels, the imagination fails before such infinite numbers, such infinite complexity. Think of the countless leaves of a forest, think of the numberless plants that have lived and died in the innumerable ages of the past, and then realise that each one of these leaves, each one of these plants, was a collection of untold myriads of atomic universes! We thus obtain a vision of Nature beside which the grandest epic ever penned by human hand seems empty and colourless.

CHAPTER XI

CARBON DIOXIDE

A COAL fire gleams and burns away. It dies down into glowing embers, and then into a handful of ash. The coal has vanished apparently into thin air. In seaports you may see men heaping thousands of tons of coal into the bodies of immense liners. Later, descending beneath the decks to where mighty engines whirl and vibrate, driving the huge vessel through the sea, you will see stokers, hot and perspiring, naked to the waist, hurling this coal into the huge furnaces which drive the boilers. The vessel starts on her voyage with thousands of tons of coal in her bunkers. She arrives at the end of her journey with this almost all gone, vanished down the throats of her furnaces, leaving only a trace of ash behind. In 1907 over a thousand million tons of coal disappeared in the same way in the fires of the civilised world. Whither has this vast quantity of coal gone? Has it been destroyed, annihilated by the very act of burning? No! Science tells us that matter cannot be destroyed in this way. These millions of tons of burnt coal still exist, they exist in the air in the form of an invisible gas. Yes, strange as it may seem, the coal in burning has turned into an invisible gas containing carbon and oxygen. Indeed, all the coal now stored in the earth was once, ages ago, united to the oxygen of the air and floated free, in the form of this gas, in the winds of the primeval world. How then did this gaseous carbon turn to solid coal? In this way: The gas was laid hold of by some living plant, which sucked it in through its leaf pores, drank it in through its rootlets, and turned it into wood. The tree died, decayed to vegetable fibre, was buried, lost its oxygen, and the carbon in it turned to coal. A man digs this coal. He throws it on

the fire—seemingly a black dead lump, but really a universe of whirling vibrating atoms. A corner, an atom of it warms until it reaches its ignition point. Then it awakens after its long sleep of ages ; each atom is seized by a hunger for that very oxygen that it lost millions of years ago, combines with it, and flies away in the form of this invisible gas. The gas thus produced is known to us all. Every time we breathe, it rushes from our lungs, produced by a process of slow combustion ; for we, too, are burning away, just like the coal, into the same gas. It is stored up in countless millions of tons in limestone and chalk, and issues from them when they are burnt to quicklime. Many and many a poor tramp, lying down by the side of a burning lime kiln to keep himself warm, has been overcome by the deadly gas pouring from it and has passed away in sleep into that land whence none return.

Every time we open a soda-water or lemonade bottle, every time champagne or beer leaps foaming forth from its glass prison into a tumbler, we see this gas rushing out in the form of millions of bubbles in the sparkling liquid, churning it into froth. In brewers' vats it is present to the extent of thousands of cubic feet, and is produced by the process of fermentation. Lastly this gas is about us, present in the very air we breathe, feeding and sustaining the great timber trees and the beautiful green vegetation which clothes the world about us.

What is this gas ? Chemists call it carbon dioxide. Its older name is carbonic acid gas. It consists of the accumulation of millions of tiny molecules speeding through space at the rate of a quarter of a mile a second, each molecule consisting of a carbon atom united to two oxygen atoms. Picture each molecule as a tiny planetary system with the central carbon atom as sun and the two oxygen atoms revolving about it as planets, and you will have a realistic interpretation of the formula CO_2 which chemists attribute to it.

The reader, too, may prepare it, and that with ease. All that he has to do is to place some lumps of marble in a bottle or flask, pour on it some acid (even a weak one like

that contained in vinegar will do; usually, however, hydrochloric acid is used), and at once, amidst a strong effervescence, he will see the gas being liberated in the form of thousands of little bubbles. The reaction has taken place according to the following equation:

$$\underset{\text{Calcium Carbonate (Chalk)}}{CaCO_3} + \underset{\text{Hydrochloric Acid}}{2HCl} = \underset{\text{Calcium Chloride}}{CaCl_2} + \underset{\text{Water}}{H_2O} + \underset{\text{Carbon Dioxide.}}{CO_2}$$

Now let us describe its properties. It is colourless. It is invisible. It suffocates. A light plunged into it is extinguished as if plunged under water. The fiercest fires may be quelled by pouring it upon them. But it extinguishes animal life in the same way that it extinguishes fire,—for are not the two allied? Men have unwittingly entered chambers and underground cellars filled with this gas, and have died. Indeed, its presence in these is a real danger, because of its great heaviness; for the gas can be poured like water from one vessel into another, so heavy is it. Soap bubbles may be made to float upon its invisible surface much as wood floats on water. Consequently it runs like water into hollows and there collects. In some parts of the world are found real death valleys, hollows shunned by man and beast, because to enter them is fatal. The reason is that carbon dioxide gas issues out of the earth from fissures in the floors of these valleys, and then fills them as water fills a lake. The most famous of these deadly depressions is the "Valley of Death" in Java. It is a deep, dark, wooded valley, the crater of an extinct old-world volcano. Tigers, wild-boars, and even men, attracted by the quiet and shelter of the spot, have been known to descend and perish miserably by suffocation. Yet the flow of gas is intermittent. Sometimes it is quite safe to enter, scarce a trace of gas being found, while at other times it wells out in large volumes and fills the valley. Its bottom is said to be strewn with skeletons of animals which have perished in its depths. Indeed, some say that human skeletons have been observed lying in the undergrowth, the remains of poor wretches who have wandered unknowingly into this death-trap. The "Death Gulch"

of Western America is another such valley. In it dead bears and animals are often found. All these localities are in volcanic regions, for in all such regions vast amounts of this deadly gas pour out into the air, not only through the throats of volcanoes, but also through the ground surrounding them, and, long after the volcanoes are extinct, the effect often continues. Thus in the woods surrounding the Laacher See, itself the water-filled crater of a prehistoric volcano, there is a depression constantly filled with this gas. Insects and birds flying to this spot perish. In this whole region the gas streams out of the earth through hundreds of outlets, and tends to collect in the cellars of houses. Some tragedies, indeed, have been thus caused. Only a few years ago Dr. Creighton, the former bishop of London, was walking round this beautiful lake, together with his wife and daughter. They were overtaken by a thunderstorm, and sought shelter. Soon a peasant girl came running to them in great trouble, saying that her sweetheart had fallen down, and she was afraid that he was hurt as she could not make him answer. She led them to a deserted building, and there at the bottom of a flight of ruined steps they could see the dim form and white face of a man. The bishop rushed down the broken steps and cautiously put his head in. The room was full of carbon dioxide and he could not breathe. Filling his lungs with fresh air, he plunged into the cellarlike building and dragged the man as far as he could. After several vain efforts at last he got him out into the open air. It was, however, too late. The man was dead.

In a cave near Naples, the Grotto del Cane, the carbon dioxide comes pouring out from the earth from fissures in the floor, and collects in the cave to the depth of two or three feet. Small animals, such as dogs, when respiring the impure air, drop senseless ; while a man breathing the pure air above this level is unaffected by the gas. If, however, the man were to sit or lie down he would be speedily overcome and suffocate.

After an eruption at Vesuvius carbon dioxide gas has been known to come off from the ground in such quantities as to poison hundreds of hares, partridges, and other small animals,

while at the same time the cellars of the houses at Naples became filled with it.

Undoubtedly the greatest masses of carbon dioxide enter the air from volcanoes, especially great torrents of it are evolved from the craters of those which exist in South America.

Now a solemn thought arises. If this death-bringing gas is even now ejected in such volumes from the interior of the earth, what must have been the case in past ages when its

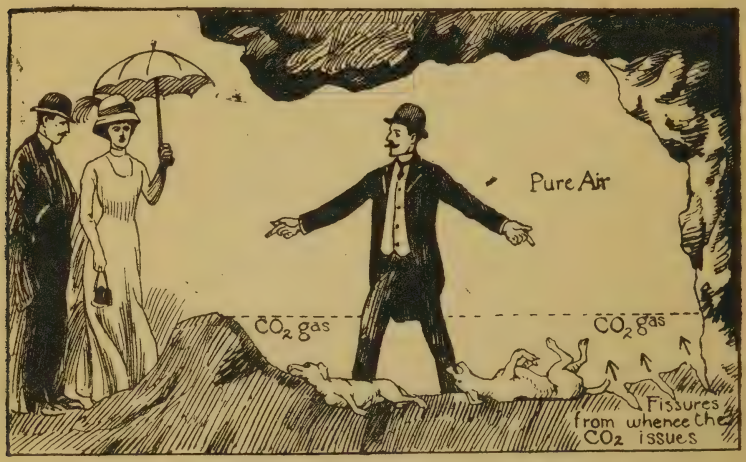


FIG. 50.—Dog Grotto near Naples (Grotto del Cane).

internal fires raged far more furiously than at present? We know that in these early times the earth often cracked across, and from the vast fissure thus produced huge torrents of molten rock and gas were belched forth and inundated the surrounding plains. It may, indeed, have happened, time after time, in these terrible ages, that such vast quantities of carbon dioxide were periodically poured forth over the land as to destroy all animal life over whole districts. Even in our own times terrible disasters have occurred owing to the belching forth of suffocating vapours during volcanic eruptions. Thus in 1783 a terrific volume of lava burst forth from the great volcano Skaptar Jokul, in Iceland, and

such huge volumes of poisonous gas were evolved simultaneously that 9,000 men, 11,000 cattle, 28,000 horses, and 190,000 sheep are said to have been suffocated! The elder Pliny was suffocated, over 2,000 years ago, by heavy gases pouring over the ground from Vesuvius when she burst into that eruption which overwhelmed Pompeii and Herculaneum. Apart from the enormous quantities of gas pouring out from subterranean depths in volcanic regions, it is well known that the ground itself evolves it. One acre of good garden land in summer evolves more than six tons of carbon dioxide. It is produced by the oxidation of organic matter in the soil. Hear what Dr. Leonard Hill says about this matter:

"Processes of oxidation are constantly going on in the soil which result in the impoverishment of the air in wells and mines, and the formation of carbonic acid. Iron pyrites (FeS_2) is decomposed by moist air, $FeSO_4$ is formed, and sulphur is oxidised to SO_2. The SO_2 combines with water to form H_2SO_3; and this, in its turn, oxidises to H_2SO_4. The sulphuric acid thus formed, coming into contact with the carbonate of lime (chalk or limestone) in the soil, evolves carbonic acid. Air impoverished by such oxidative processes becomes insufficient to support combustion, when the oxygen tension falls from the normal 21 to 17.3 per cent. of an atmosphere. The presence of such impoverished air is shown by the extinction of a candle or lamp. Pure choke, or "black-damp," as such deoxygenated air is called, contains 85 to 95 per cent. nitrogen, and 15 to 5 per cent. carbonic acid. The amount of black-damp formed in mines is enormous, 2,000 to 5,000 cubic feet per minute is a common quantity, and the oxidative processes which produce it are the chief source of heat in mines (Haldane). Choke-damp comes out from the soil into the mine or well, especially when the barometer is falling."*

It is no wonder, therefore, that old wells, and shut-in subterranean passages, such as occur under old castles and ruins, and in disused mines, often get filled with the gas. Any one walking incautiously into one of these places may easily be suffocated, and all the more easily because the discomfort felt by the person gradually advancing into increasingly bad air is often very slight, and gives little or no warning of danger. Consciousness is suddenly lost, and

* Lecture delivered at the North Staffordshire Institute of Mining and Mechanical Engineers, January 13, 1908.

unless the victim can be instantly removed to good air, his life is in great danger. Hence before entering into such a cellar the air must be always tested to see whether a candle will burn in it.

Although pure air contains only 0.03 per cent. of carbonic acid, the air of crowded halls may increase to 0.5 per cent. No noticeable effects, however, are produced until the percentage of gas increases beyond 3 per cent., when a painful headache is often caused to those breathing such air. An increase beyond this brings about panting, and greatly diminishes the capacity for work, death ensuing rapidly when the percentage reaches 25 per cent. and over. On holding the breath as long as possible, as when diving under water, the air of the lungs is found to contain about 10 to 12 per cent. of carbon dioxide. Normally there is about 5 per cent. of carbon dioxide in human breath. Carbonic acid is used by hygienists as an indicator of efficient ventliation, not because it is poisonous, but because it serves as an index of the contamination of the air by bacteria and the effluvia which arises from the bodies of men. It is these effluvia, and not the carbonic acid, which have such a bad effect on health.

Men and animals are continually breathing out carbon dioxide into the air in very considerable quantities. All animals, in fact, are slowly burning away in the oxygen of the air, and it is the heat produced by this means which keeps our bodies warm and sustains life. Men, bulls, sheep, horses, and other animals have been placed in enormous hermetically-closed jars, and by carefully analysing the gases evolved during respiration, it has been found that a man breathes out 900 grams (nearly two pounds) of carbon dioxide per day, or about twenty-two tons in a lifetime of seventy years ! The whole human race throws daily into the air over 1,000,000 tons of this gas ! When we consider the countless millions of men and animals who have lived and died during the innumerable ages of the past, we can gather some dim idea of the enormous quantities of carbon dioxide which have been poured into the air from this source. Yet this is not the only, nor even the chief source of the gas. In 1907 there

were burnt no less than 1,080 million tons of coal, which must have produced well over 3,400 million tons of the gas, or nearly ten times as much as was evolved in the breath of the whole human race during the same period of time! By far the greatest quantities of carbon dioxide are poured into the air from the earth's interior through the mouths of volcanoes, being thrown out from the cooling silicates in the upper layers of the earth's body.

Now this volcanic action has been going on for ages, which stretch back in a dim illimitable vista as far as the geological history of our planet takes us. For many hundreds of millions of years, both animals and volcanoes have been continually belching forth this gas; and yet we find that there is only three volumes of the gas in ten thousand of air —a quite minute percentage. So small is this quantity that at the present rate at which the carbon dioxide is being poured into the air a few hundred years, certainly far less than 350 years, would double the proportion in which it is contained in air. It is obvious, then, that there must be agents which remove the carbon dioxide from the air almost as swiftly as it is thrown into it. One such agent, and perhaps the chief one, is the process of weathering. The carbon dioxide is absorbed by rocks. The earliest and most primeval rocks, those which are cast forth by volcanoes, and which formed the molten glowing surface of the early world, consist of compounds of silicic acid with alumina, lime, magnesia, iron, and sodium. These stones are gradually attacked by the carbon dioxide of the air in such a manner that the lime, magnesia, and the sodium form soluble carbonates, which are washed away by the streams and rivers into the sea. Here the millions of sea animals and plants assimilate the magnesium and calcium carbonates and deposit it as shell or coral around them. Vast rocks are thus built up of these precipitated carbonates; sometimes they occur in beds thousands of feet thick, and covering hundreds of thousands of square miles of the earth's surface. In them are stored enormous quantities of carbon dioxide, all of which was absorbed from the atmosphere by the process of weathering. Högbom cal-

culates that in the limestones and dolomites there exist at least 25,000 times as much carbon dioxide as is at present in the atmosphere. Chamberlin comes to about the same result. In other words, the amount of carbon dioxide withdrawn from the atmosphere in past times by the process of weathering and now stored up in the rocks in the form of carbonates exceeds the whole present volume of the atmosphere some 750 times! The wonder grows when we learn that these estimates are probably far too low. The amount of carbon dioxide which must have existed in the early atmosphere of the earth was simply enormous, and baffles all attempts to realise clearly. These huge original amounts have all disappeared within the earth's interior, chemically combined with the rocks, except the minute fraction which now exists in the atmosphere. Even to-day this absorption of carbon dioxide is going on, and in consequence of it the mightiest cliffs and hardest rocks rot away in time, and are converted into soft soil on which vegetation can take root and flourish.

There is also another process which takes from the air its carbon dioxide; and that is vegetative growth. In early spring, no doubt you have often been struck with the beauty of the rich green colour of a sun-lit landscape. This green, so beautiful and soft, is due to the presence of a mysterious colouring matter called "chlorophyll," whose exact constitution has not as yet been made out. When sunlight gleams on this what really happens is that myriads of minute pulsations of the ether (we call them light) burst each second upon this complex chemical compound, just as waves break upon the sea-shore, and set its atoms swinging. When so agitated the chlorophyll possesses the power of sucking in from the air the carbon dioxide it finds in it, decomposing it by means of a series of very complex changes not yet understood, absorbing the carbon and evolving the oxygen, thus:

$$\underset{\text{Carbon Dioxide}}{CO_2} = \underset{\text{Carbon}}{C} + \underset{\text{Oxygen.}}{O_2}$$

Holmes has expressed this fact in beautiful language:

"The great sun
Girt with his mantle of tempestuous flame
Glares in mid-heaven; but to his noontide blaze
The slender violet lifts its lidless eye
And from his splendour steals its fairest hue,
Its sweetest perfume from his scorching fire."

Now notice a wonderful thing about this action. This carbon dioxide is a very stable body. A very high temperature of 1,200-1,300° C. is required to partially decompose it. Yet the plant performs this difficult operation at ordinary temperatures, utilising the energy of the sunlight! We see, therefore, how immensely more potent than ourselves to effect chemical change is that mysterious everchanging complex of atoms called living matter. Watching on a sunny summer day the quivering leaves in a woodland district or the waving blades in a wheat field, we might easily imagine that we are contemplating an ideal state of lazy enjoyment. But never were we more mistaken. All the time the surface of the leaves are in ceaseless activity, drinking in the carbon dioxide through every pore, decomposing it by mighty forces at work within the leaves, rending its atoms apart, and storing them up in its body.

This has been going on from times immemorial, ever since the first green plant came into existence hundreds of millions of years ago. The small amount of carbon dioxide in the air thus feeds and supports all the rich vegetation which clothes our planet with a garment of green. And indirectly it supports us as well, for we, like all other animals, depend for our nutriment upon the plant world. That Nature can make so much out of so little is, indeed, truly wonderful.

The fixation of carbon dioxide by plants is part of a vast cosmic process going on ceaselessly, not only in our world but perhaps in myriads of the innumerable worlds of space. You must all know that the sun is a mighty white-hot globe, over a million times vaster than the earth. Its surface is in a state of terrific movement. Vast flames of gas and vapour rush up each second at the rate of hundreds of miles a second to the height of many thousands of miles. In consequence of this there streams from it each second

incredible amounts of heat and light into the endless depths of space. Think, in a single second there rushes from the sun as much heat as could be produced by the combustion of 16,400 billion tons of coal! The earth is bathed in this mighty stream of heat and light, and has been for ages. True, it only receives the 2,128,000,000th part of it. Yet, excepting the tides and the energies depending upon the internal heat of the earth, to it is due almost every form of energy upon this globe. All movement of air and water, from the mighty devastating hurricane to the gentlest summer breeze, from the thundering cataract to the ripple on the sea, all snow and rain, all thunder and lightning, are but the products of this solar energy. Beating upon the earth for untold ages it has produced—how we know not—a responsive action.

"The whole earth set herself the task of storing up this light which streams earthwards from the sun, of converting the most volatile of all power into a rigid form, thus preserving it for her purpose. To this end she overspread herself with organisms which, living, take in the solar light, and by the consumption of its energy incessantly generate chemical forces. *These organisms are plants; the vegetable world is the reservoir in which the fugitive solar rays are fixed, suitably deposited, and rendered ready of useful application.*"*

We have just seen how they fix these rays. It is believed by many chemists that all the oxygen now in the air was thus set free by the ancient action of sunlight and green vegetation on the carbon dioxide in the air. The carbon is at first stored up in the plant tissues; thence it is devoured by plant-eating animals (and consequently by flesh-eating, which prey upon the herbivorous), and in their bodies is oxidised or burnt again to carbon dioxide, and breathed out again into the air, only to be absorbed again by plants, split again by sunlight, and again taken into the animal body. Thus there occurs in Nature a ceaseless circulation of carbon, a circulation caused and maintained by the sun's rays. The carbon now in our bodies, in every piece of wood and grass about us, has thrilled in the living bodies

* Mayer's words are here quoted, from Proctor's "Old and New Astronomy," p. 335.

of untold myriads of long-vanished races of animals and plants, races stretching back in almost infinite succession into the dim mists of past time. As the ceaseless ages roll onwards like an ever-flowing tide, sweeping us away and reducing our bodies to their component atoms, our carbon will continue to circulate long after our very memory has vanished from the world, in the bodies of animals and plants, living in a sun-lit world and enjoying life, millions of years hence ! Very strange, but still quite true.

Thus we realise that all vegetation, and indirectly, all animal life as well, owes its existence to the sun's rays acting on the carbon dioxide in the atmosphere. Without this mighty stream of energy pouring continually upon the earth, no living thing could exist in the waters, in the air, or on the land. Man himself owes all power, his food, his coal, his navies, trains and great artillery, to the sun's amazingly profuse yet steady emission of light. Yet our tiny earth is but a dust speck floating in infinite space ; and the suns of the universe which sparkle and gleam down at us at night emit light quite as profusely as, and often on a far vaster scale than, our sun. We cannot but believe, then, that the dark little worlds wheeling round them are fitted with similar contrivances for arresting and storing the vast streams of energy rushing ceaselessly past them into the void and silence of space.

Do those processes which remove the carbon dioxide from the air exactly balance those which throw it into the air ? The answer of science is : No ! Most careful investigations of American geologists, amongst whom Chamberlin may be especially mentioned, have shown that the carbon dioxide is being absorbed by rocks at such a rate that it will require a period of time between 5,000 and 18,000 years to use up that which is already in the air. The rate at which carbon dioxide is being actually produced by the burning of coal, petroleum, etc., exceeds this fourteen times over ! Then there still remains the absorption of the gas by plants to be accounted for. The famous chemist Liebig estimated that the amount of water-free organic matter produced by an acre of ploughed land, meadow, or forest, is about the

same, namely, about one ton weight per year in Central Europe. Now, in many tropical countries the growth is far greater than this, while in other parts, in the deserts and arctic regions, it is much less. Arrhenius, therefore, assumes that Liebig's number will hold as an average number for the whole solid land surface of the globe, and calculates on this basis that plants absorb yearly no less than 13,000 million tons of carbon from the air, or about the fiftieth part of the carbon dioxide in the whole atmosphere. Since this is twelve times greater than the amount of carbon given to the air by the burning of coal, it is clear that if all the plants were to deposit all their carbon in the form of peat or coal, in a very few years the air would be robbed of every bit of its carbon dioxide, and consequently all plant life, and with it all animal life, would come to a more or less abrupt end. Luckily for us, however, plants do not do this. Of the total amount of carbon taken by them yearly from the air only a fraction of a per cent. is deposited as peat or coal, and so is lost. The rest goes back, either by oxidation or decay, into the atmospheric carbon dioxide again. It is, indeed, believed that the amount of carbon dioxide in the air, far from diminishing, is actually increasing, and that pretty rapidly. The enormous and increasing amount of coal burnt every year is probably throwing more carbon dioxide into the air than is removed by the agencies above discussed. Besides this, volcanic action, the effects of which have been especially disastrous of recent years, seems to be increasing, and therefore the amounts of carbon dioxide yielded to the air by this means is also increasing. One circumstance which points to this conclusion has been discussed by Arrhenius.* He shows that the amount of carbon dioxide over the sea and small islands is about 10 per cent. less than that over continents. In other words, the sea is steadily absorbing carbon dioxide. Now, if the amount of this gas had remained unchanged in the air for vast periods of time, the amount of carbon dioxide dissolved in the sea would have had plenty of time, through absorption, to come into a state of equilibrium with that found in the air. If the sea is absorbing

* Das Werden der Welten. p. 57 (1908).

carbon dioxide from the air, this shows that it stands in equilibrium with an air containing less carbon dioxide than our present atmosphere contains. In other words, within recent years the amount of carbon dioxide in the air has increased.

If this be so, we must next inquire whether this will have any influence upon us, and upon plant life, and upon the weather. Arrhenius answers: Yes, and that a favourable one. In the first place an increased amount of carbon dioxide will greatly increase the mean temperature of the atmosphere all over the earth's surface, thus making it milder. In the second place, there will be more carbon dioxide in the air for plants to feed on, and thus vegetation will tend to become more luxuriant. It appears that this carbon dioxide has a wonderful power of absorbing non-luminous heat rays, and of letting visible light rays go through. Thus the rays of the sun can reach the earth, strike the soil, warm it, and thus be converted into invisible dark heat rays such as are emitted from a kettle of boiling water, or from hot steam pipes; but when these invisible heat rays try to get away from the earth again, they cannot. The carbon dioxide in the surrounding air catches them and bottles them up, and the greater the amount of carbon dioxide in the air the greater is this effect, and so the higher the general temperature of the atmosphere. Arrhenius has calculated that if all the carbon dioxide in the air—it is only present to the extent of 0.03 per cent.—be removed the temperature of the earth's surface would sink nearly 21° C. As a consequence of this lowering of temperature the quantity of water vapour in the air would diminish, thereby causing an almost equally great further fall of temperature, and converting the whole earth into the state of the arctic regions. If the amount of carbon dioxide in the air were to sink only half its present amount, this would be sufficient to lower the general temperature some 4° C., and thus give to England the temperature of Sweden.

On the other hand, supposing the amount of carbon dioxide were to double itself in the air, the general temperature would increase by 4° C. If it were to increase fourfold, the

rise of temperature would be actually 8° C., and restore to England the semitropical climate she is known to have possessed in very ancient times.

Now notice how the sciences of chemistry and geology are interwoven. It is well known that in geological history very great temperature variations have taken place. Immediately preceding historical times was a period when the average temperature was 2° C. higher than at present. This is known because we find the fossil remains of shrubs like the hazel-nut flourishing in places where, on account of the more severe temperature conditions now prevailing, they cannot exist at all at the present time. Before this time was the terrible glacial age, which covered all Central Europe and Great Britain as well, with a vast ice-sheet, sometimes thousands of feet thick, covered them up, buried them, and turned them into desolate arctic wastes, such as Greenland is now, and held them so for a hundred thousand years! Before this time there went another series of long, long ages, when a tropical climate flourished, when tropical plants blocked up the Thames valley, and tropical animals wandered over the country, and when the temperature was 8 or 9° C. higher than at present. These are truths proved beyond all doubt by science. What caused these great temperature changes? Many chemists and geologists, among whom may be mentioned Högbom, Stevenson, and Arrhenius, assert that it was the varying amount of carbon dioxide in the air.

We know that the amount of carbon dioxide now in the air is so small that actually the burning of coal in industrial processes pours into it every year the six-hundredth part of its present amount, and therefore would double the quantity in the air in some six hundred years. It is true that the sea here acts as a mighty regulator and absorbs nearly five-sixths of the carbon dioxide thus produced, yet, in spite of this, it is certain that the minute proportion of carbon dioxide can be noticeably increased by industrial processes in the course of a few hundred years. This alone proves that there is no great constancy in the amount of carbon dioxide in the air, but that it has probably undergone great

variations in past times. Indeed, in times of great volcanic activity such huge volumes of this gas are poured into the air as would certainly modify the proportions present. Now it has long been known that in the different phases of the world's geological history volcanic action has been very unequal. There have been periods of volcanic repose, which have lasted for hundreds of thousands of years, followed by periods of exaggerated activity, when vast quantities of lava were poured forth simultaneously in the most widely separated regions. Professor Frech, of Breslau, has, indeed, recently endeavoured to prove that periods of violent volcanic action have always coincided with a warm tropical climate, while periods of volcanic rest correspond with ages in which a low temperature reigned. In the great ice-age itself volcanic action almost entirely died out, while both the periods at the beginning and end of the great tertiary age were extremely warm, and at the same time characterised by vast volcanic outbursts such as we have now no conception of. The parallel can be extended into still earlier periods of the world's history.

An increased amount of carbon dioxide in the air not only warms the earth's surface, it also makes plants grow more luxuriantly. This was shown by careful experiments carried out in 1872 by the Polish botanist Godlewski. He experimented with two plants, Typha latifolia and Glyceria spectabilia, and he showed that they grow proportionally to the amount of carbon dioxide in the air until this became more than one per cent. The assimilation slowly increased until it reached a maximum when, in the case of the former plant, the percentage of carbon dioxide reached 6 per cent., and in the case of the latter, 9 per cent. On increasing the percentage of carbon dioxide beyond this the assimilation slowly decreased again. In other words, if we double the amount of carbon dioxide in the air, we double the rate of metabolism going on in the plant ; but this increased amount of carbon dioxide would cause the temperature of the earth's surface to increase 4° C., and this would increase the chemical changes proceeding within the body of the living plant in the ratio of 1 : 1.5. In other words, by merely doubling the

amount of carbon dioxide in the air we should cause plants to absorb it three times as rapidly as they do at present, and thus grow far more luxuriantly. It is easy to understand, therefore, why in the Carboniferous epoch plant life flourished on such an immense scale. In all probability the percentage of carbon dioxide in the air was considerably higher than at present, and this, combined with the increased temperature thus produced, caused the whole world to become a vast greenhouse, and produce those masses of vegetation whose remains to-day we use as coal.

It has often been said that we are rapidly using up the valuable and irreplaceable coal buried in the earth, and that the time will come when it will be all exhausted. Nevertheless, it should not be overlooked, that, as Arrhenius points out, the increased amount of carbon dioxide thrown into the air by this means may, in the course of centuries, so modify the climate, so improving that of the more temperate regions, that the earth may ultimately be capable of bearing a much greater weight of harvest per acre than it can at present. Even at the present rate of coal consumption there is still enough to last the earth for five hundred years to come, and long before that time some way might be found for doing largely without coal. In any case, our descendants may safely be left to solve the problem in their own way.

Carbon dioxide is easily soluble in water, dissolving to form a weak acid called carbonic acid, of the formula H_2CO_3. Rain washes it down from the air, and, as we have already pointed out, the acid water then slowly but surely eats away the hardest rocks, dissolving out their more soluble portions and leaving behind the insoluble. Perhaps of all the rocks occurring in Nature, chalk, limestone, and marble are the most soluble in water containing carbon dioxide. They are all modifications of the same substance, calcium carbonate, $CaCO_3$. They are composed of the light silvery metal calcium (Ca) united with carbon and oxygen in the proportions indicated by the formula. Indeed, it is quite an easy matter to show their solubility experimentally in the laboratory. If we pass a current of carbon dioxide gas through lime-

water (slaked lime dissolved in water), we get at once a milky precipitate of calcium carbonate or chalk :

$$\underset{\text{Carbon Dioxide}}{CO_2} + \underset{\text{Lime-water}}{Ca(OH)_2} = \underset{\text{Calcium Carbonate}}{CaCO_3} + \underset{\text{Water.}}{H_2O}$$

If, however, we continue the stream of gas, the chalk will redissolve again, and the solution will again become clear. The reason of this is that the carbonic acid, H_2CO_3, which accumulates in the water as the gas passes through, gradually combines with the precipitated chalk to form a soluble compound called calcium bicarbonate, thus :

$$\underset{\text{Chalk or Calcium Carbonate}}{CaCO_3} + \underset{\text{Carbonic Acid}}{H_2CO_3} = \underset{\text{Calcium Bicarbonate.}}{CaCO_3.H_2CO_3}$$

Hence water rich in carbon dioxide will dissolve rocks like chalk, limestone, or marble in much the same way, though to a less extent, that water dissolves sugar. Water which contains chalk dissolved in it is termed " hard." When we boil it for some time it becomes milky, because the heat decomposes the bicarbonate, driving off the CO_2. The chalk is then precipitated, thus :

$$\underset{\text{Calcium Bicarbonate (Soluble)}}{CaCO_3.H_2CO_3} = \underset{\text{Calcium Carbonate (Insoluble)}}{CaCO_3} + \underset{\text{Water}}{H_2O} + \underset{\text{Carbon Dioxide.}}{CO_2}$$

This fact explains why it is that kettles and boilers get gradually covered over with a layer of chalk when hard water is boiled in them. In the case of large boilers this constitutes a real danger, and greatly diminishes their life and effectiveness.

The same deposition of chalk occurs, but far more slowly, if the water partially evaporates at ordinary temperatures.

These facts have a great natural importance ; for many regions of the earth are composed almost entirely of limestone rocks ; and in such districts ceaselessly, century after century, these rocks are dissolving away under the influence of the carbon dioxide dissolved in rain water. This solution is not

only proceeding on their surface, but in their interior as well. Every shower of rain which filters through the crevices of a limestone rock dissolves away some portions of it. Moreover, waters deep under the earth are often saturated with carbon dioxide under great pressure, for this gas is being continually evolved from underground regions. Water under such conditions will dissolve no less than three grams of chalk or limestone per litre, or about two pounds in a cubic yard !

The amount of lime which these subterranean waters, nay rivers is the better term, gnawing underground day and night, year after year, century after century, for thousands of years, remove in the course of time is stupendous. One can, therefore, scarcely wonder at the enormous size of the caves to be seen in limestone districts in many parts of the world. Indeed, such regions are often not only honeycombed with mighty caverns filled with rushing waters, but in them great rivers suddenly and without warning plunge underground through holes in their beds, and run deep below our feet

> " Through caverns measureless to man
> Down to a sunless sea."

Thus in Spain the Guadiana loses itself in a flat country in the midst of an immense savannah. In the vast limestone formation which extends through Carinthia, Carniola, Istria, Dalmatia, Albania, and Greece, the whole country is perforated like a sponge by an intricate system of subterranean watercourses. Here may be seen the wonderful sight of rivers rushing forth out of the earth from one cavern and disappearing again into another, thus flashing into daylight but for a brief instant during an underground course of many miles. The caves of Adelsberg, Planina, and Upper Laibach, in Carniola, are traversed by the same river, which, losing its name every time it plunges into a new subterranean channel, is called, first the Poik, then the Unz, and finally, the Laibach.

The courses of these subterranean rivers exhibit a wonderful variety of interesting underground scenery. Sometimes

they form high cataracts thundering down into mighty abysses ; sometimes they expand into dark and melancholy lakes, over whose placid waters generally not the least breath of air stirs, though sometimes their surfaces are rippled by wind pouring in through unseen chasms which lead to the surface. Where beds of hard stone oppose the flow of the water all that it can do is to hew out one narrow aperture, but where the rock is soft huge chambers are excavated, whose roofs, hundreds of feet above, are lost in gloom which no torch can penetrate. The water spreads widely in the large cavities, then, contracting its stream, it rushes through each defile as through a sluice. Each stream is thus a series of widenings and contractions, a succession of lofty halls and narrow tunnels often entirely filled with swiftly flowing water, a fact which makes their exploration both difficult and dangerous.

Among the bold explorers who have sailed down unknown subterranean rivers may be mentioned Dr. Schmidl. In a canoe he trusted himself to the dark streams of Carniola, near the head of the Adriatic, and was rewarded with many a scene of incomparable beauty.* On one journey he made his way up the famous cave of Planina, through which flows the Poik, a river at all times deep enough to float a boat. He reached on foot a magnificent dome about 600 feet from the entrance ; but here the river filled the whole width of the cave, and the bold adventurer had to push onwards in his canoe. He soon reached a portal some fifty feet high and twenty-five feet broad, with proportions as symmetrical as if made by man, and beyond this, in the darkness, heard the thundering roar of a mighty subterranean cataract, the herald of still grander scenes. Gradually the portal widened, and the astonished explorer suddenly saw before him a dark and dismal lake, about 250 feet long by 150 wide. The roof was so high that the light from a few torches failed to reach it, while the dark walls rose perpendicularly from the black waters, and extending upwards out of sight, presented a melancholy but imposing sight. Beyond the lake the cave

* A full account of these wonderful journeys of Dr. Schmidl may be found in his book " Die Höhlenkunde des Karstes," Vienna, 1854.

was seen to divide into two arms, down which flowed two streams, whose waters, mingling, gave rise to the lake.

Pushing forward, Dr. Schmidl passed into the unknown regions beyond. In the left branch of the cave, into which he penetrated more than a mile, the boat had to be unloaded more than eleven times on account of the reefs that obstructed its passage, while the explorer, wading through the water, dragged it over the shallows. Once, indeed, when the waters disappeared with a terrible roar under a large mass of rock, the boat had to be taken to pieces and rebuilt on the other side.

At last they reached a gloomy hall with a lofty circular dome, filled by a lake 180 feet long, and forty to forty-five feet deep. From out of a neighbouring chasm rushed ceaselessly a violent cold wind. Beyond this lake they entered a dry chamber called by Dr. Schmidl, "The Stalactical Paradise." It was the first time that human eyes had ever beheld it. Here whole groups of stalagmitic cones, of all shapes and sizes, some like tiny icicles, others six feet high and thick as a man's waist, rose from the ground. "The Stalactical Paradise remained untouched," says Dr. Schmidl.* "I asked my companions not to break off the smallest fragment of spar as a memorial of our visit, and they all joyfully agreed to this. We carefully avoided trampling down any of its delicate ornaments, and left it with no other memorial than our admiration of its beauty. The nymphs of the grotto will no doubt have forgiven us for having intruded upon the sanctuary, where for countless centuries they had reigned in undisturbed solitude and silence."

The other branch of the cave was also explored and extends for miles underground. "No description can do justice to the fascination of this subterranean journey," continues Dr. Schmidl. "In parts the roof is ornamented with coral-shaped draperies of snow-white stalactites, but more generally the walls are mere black naked stone. Here and there streamlets gurgle down their sides, and, together with the melancholy trickling of single drops of water from the vault, alone break the silence of the dark interminable cave. The

* Die Höhlenkunde des Karstes.

breathless attention we bestowed on the navigation of our boat and on the wonders which surrounded us held us speechless, and we glided in silence along through the dark waters, that now for the first time since they began to flow reflected the glare of a torch."*

Marvellous as these caves are there are others which equal or even exceed them. For example, there is that wonderful cave of Caripé in Venezuela, which penetrates the face of a limestone cliff, crested with enormous flowering trees, festooned with some magnificent tropical creepers; straight like the nave of a great cathedral, for fourteen hundred feet, runs this magnificent arch. Out of it runs a stream, and along the banks of the stream, as far as the glowing tropical sunlight strikes in, grow wild bananas and palms. Beyond that the cave goes on, with subterranean streams, cascades, and halls, no man yet knows how far. One explorer in 1876, taking with him a powerful magnesium light, went in further than any one before; and in one place, when he lighted up the magnesium, he found himself in a vast hall full 300 feet high, a hall far vaster than the dome of St. Paul's. And thus he saw what no other human being had ever seen before, for no ray of light had ever struck on that tremendous roof in all the ages since the world was made.

" But if he found out something which he did not expect, he was disappointed in something which he did expect. For the Indians warned him of a hole in the floor (which they told him) was an unfathomable abyss. And lo, and behold! when he turned the magnesium light upon it, the said abyss was just about eight feet deep. But it is no wonder that the poor Indians, with their little smoky torches, should make such mistakes; no wonder, too, that they should be afraid to enter far into these gloomy vaults; that they should believe that the souls of their ancestors live in that dark cave; and that they should say that when they die they will go to the Guacharos, as they call the birds that fly with doleful screams out of the cave to feed at night, and in again at daylight to roost and sleep. Now, it is these very Guacharo birds which are the most wonderful part of the story. The Indians kill them and eat them for their fat, although they believe they have to do with evil spirits. But scientific men who have studied these birds will tell you that they are more wonderful than if all the Indians' fancies

* Dr. Schmidl, loc. cit.

about them were true. They are great birds, more than three feet across the wings, somewhat like owls, somewhat like cuckoos, somewhat like goatsuckers; but, on the whole, unlike anything in the world but themselves; and instead of feeding on moths or mice, they feed upon hard fruits, which they pick off the trees after the setting of the sun. And wise men will tell you that the making of such a bird as that, and giving it that peculiar way of life, and settling it in that cavern, and a few more caverns in that part of the world, and therefore the makings of caverns ready for them to live in, must have taken ages and ages, more than you can imagine or count."*

North of the town of Adelsberg, in Austria, the stream of the Poik suddenly flows through a mighty doorway into the heart of a mountain, and gives rise to a wonderful cave, known as the "Grotto of Adelsberg," curious on account of its immense size, its innumerable white and rose-coloured stalactites, and the torrent which runs roaring through it. Certainly its vast compartments, its abysses wrapt in darkness, and the eternal echo of its rushing waters produce on visitors an awe-inspiring effect. One part of it, deep in the heart of the mountain, opens out into a stupendous hall, a hall so vast that its mighty roof spans 630 feet at a single sweep; in its centre ascends a perfect forest of stalagmite columns and white needles, produced by the dripping waters of many ages. This cave is believed to be the original of the one Coleridge describes so vividly in his poem, "Kubla Khan":

> "Five miles meandering with a mazy motion
> Through wood and dale the sacred river ran,
> Then reach'd the caverns measureless to man,
> And sank in tumult to a lifeless ocean."

It is well known that in the island of Cephalonia, in Greece, the sea has for generations been flowing down a crack in the limestone, in a volume sufficient to be used for working corn-mills. Consequently enormous caverns must exist here deep underground, but which are quite unreachable by man.

Perhaps the greatest limestone cave known in all the earth is the "Mammoth" cave of Kentucky. It may truly be called a subterranean world, having a system of lakes and

* "Half Hours Underground" (Dalby, Ibister and Co.), p. 325.

rivers. A network of galleries and passages, over 217 miles in length, cross and recross each other, going down to an immense and not yet ascertained depth. The main road runs under wonderful natural arches and domes for six miles, being a deserted bed of a subterranean river. In the gloom comes the loud ticking of the falling water as it drops

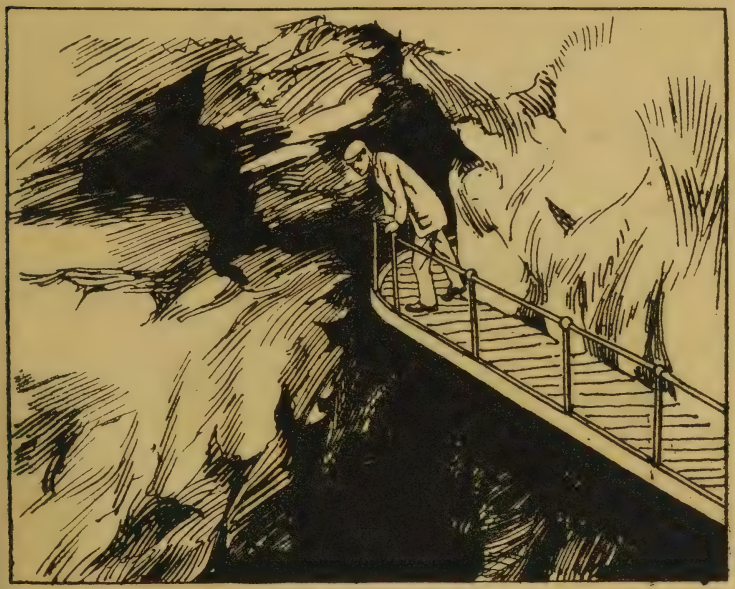


FIG. 51.—The Bottomless Pit. A terrible chasm in the Mammoth Cave now crossed by a bridge.

into the basins it has worn for itself in the solid rock. In some places are dangerous abysses. The Side Saddle Pit goes down a hundred feet sheer, like a quarry gaping by the path side. The Bottomless Pit goes down 175 feet and more, and is crossed by a bridge. In Gorin's Dome the floor far below is covered with water an acre in area. The perpendicular walls rising out of sight are draped with three immense stalagmitic curtains, rising one above the other. There is a dark sullen river slowly flowing at an immense depth below the ground towards an unknown destination.

This river, called Echo River, is in places some two hundred feet wide, and is navigable for three-quarters of a mile, when it disappears beneath an overhanging rock, and is lost to sight in the bowels of the earth. In this river wonderful blind fish are caught, fish which have lived for such ages in the dark that the race has lost its power of using its

FIG. 52.—Voyaging down the sunless waters of the Echo River, Mammoth Cave.

eyes! A fleet of boats sails on its dark waters and conveys visitors along the whole of its navigable length.

One distant and dangerous abyss, called the Maelstrom, was first explored by a boy, Prentice by name. He was let down by a rope into the pitch-black depths. Down he went, where never man had been before, swinging over the giddy gulf as he went. Half way down he swung into a waterfall which nearly put out his light. Soon he was through the spray, and stood on solid rock 190 feet below. As he came up he stopped at a niche, and, leaving the rope,

wandered off to explore a series of galleries and halls which opened out on to it. When he returned—oh horror!—the rope had swung off the stalactite, and was dangling beyond his reach! The plucky lad, however, did not faint; he took the wires off his lamp, twisted them together into a hook, fished back the rope, and signalled aloft to hoist away!

The whole extent of the cave has not yet been explored. There exist miles and miles of unknown passages where no human foot has ever trod. Indeed, many of these passages are extremely dangerous, and the explorer runs the risk of being crushed by falling rock. Doubtless vast halls and immense galleries exist along the further unknown course of the subterranean river, which must run at length into the sea, many miles away, by subterranean passages, and so the known part of the cave, vast as it is, can only form a minute fraction of the unknown whole.

This cave once formed a retreat for savage tribes; for skeletons of men of an unknown race have been found in it underneath layers of stalactite. Its existence, however, had been forgotten for centuries, and so it came about that it was re-discovered only a hundred years ago by a hunter named Hutchins.

The story runs that he had badly wounded a bear and was in hot pursuit of it when the animal disappeared in the dense undergrowth. Following up the trail of bloodstains he found that they disappeared in a low opening almost hidden by a dense vegetation. He boldly entered, and to his astonishment found himself in this vast underground palace.

Many caves are without any visible communication with the external world. Others have entrances so narrow, so overgrown with vegetation, that they have only been discovered by the merest chance. Sometimes workmen in a quarry have been suddenly surprised at meeting with a hole in the rock, which leads to subterranean depths. Sometimes the digging of wells or cellars, the boring for mines or artesian wells, has revealed the existence of great underground caverns. Undoubtedly a vast number of caves must still be totally unknown. Many, indeed, may be hollowed out at such vast depths as to be for ever inaccessible to man.

Indeed, we have much evidence tending to show that under the earth vast caverns actually occur. When their roofs collapse great lakes are sometimes formed over their sites. It is believed that this is the origin of the wonderful Lake

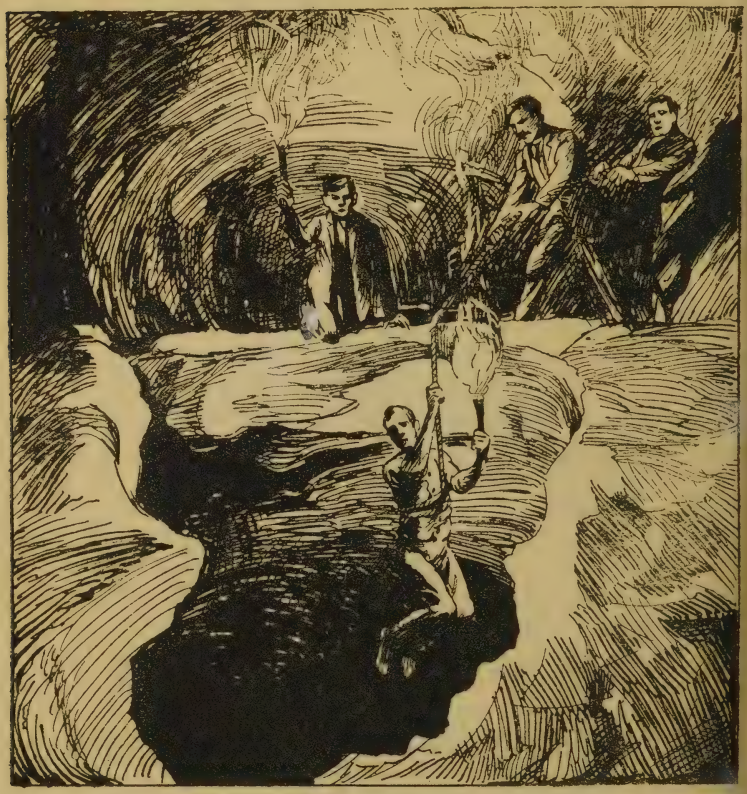


FIG. 53.—Into the Unknown. The boy Prentice exploring the Maelstrom, a deep abyss in the Mammoth Cave.

Zirknitz in Carniola. It is a great depression in the ground which is often half full of water. At certain times of the year, however, its waters suddenly vanish through chasms under water, sucking down the fish with it. After some months the water again boils up from the underground

depths, sometimes with such force as to hurl great rocks up with it, in the manner described by Coleridge in the lines:—

> "And from this chasm, with ceaseless turmoil seething,
> As if this earth in fast, thick pants were breathing
> A mighty fountain momently was forced:
> Amid whose swift half-intermitted burst
> Huge fragments vaulted like rebounding hail,
> Or chaffy grain beneath the threshers' flail:
> And 'mid these dancing rocks at once and ever
> It flung up momently the sacred river."

But the wonderful part of the story is that the fish which have been sucked down into some great subterranean lake are again brought back uninjured by the rush of waters to the surface. Not only is this so, but it is said that live wild ducks who went down with the waters small and unfledged are brought up again months later when the waters boil up to the surface, and are then full-grown and fat, with water weeds and small fish in their stomachs, showing that they had plenty to feed on during their stay underground, besides having abundant quantities of air to breathe. They have, in fact, been swimming about in great dark subterranean halls. The birds are blind when they reach the surface from having been so long in utter darkness, but after a while their eyes get right, and they fly away like other birds. Indeed, the whole of this district is honeycombed with underground passages hollowed out by running water. Even small earthquake shocks can arise by the sudden collapse of the roofs of such caverns deep in the earth. Thus, in September, 1814, near Alaix, the ground emitted for twenty-four hours a sound like the thunder of heavy artillery; then with a mighty crackling noise, it sank thirteen feet for a breadth of nearly 264 feet, —just the sort of effect that would be produced on the surface from the collapse of an underground hall. Not far from the town of Wagstadt, in 1827, a tract more than two acres in area sank in a similar way with a crash like thunder, and shook the land around far and wide. Indeed, if the huge "Salle du Calvaire" in the Adelsberg cave, whose roof spans 630 feet, were to collapse suddenly, several acres of land on

the surface above would be depressed some feet in exactly the same way.

That the infall of enormous caverns in the earth, which have been hollowed out by the removal of salt, gypsum, calcium carbonate, and silica in vast quantities by running water, are the cause of earthquakes was taught by the Greek Philosophers over 2,400 years ago. Lucretius in his poem "De Rerum Natura," thus grandly describes this idea:

"Learn now, the cause of earthquakes; the interior of the earth is, like the surface, filled with winds, caverns, lakes, precipices, stones, rocks, and a large number of rivers, whose impetuous waves hurry along in their course numerous submerged blocks. The shakings of the surface of the globe are occasioned by the falling in of enormous caverns which time has succeeded in destroying. Whole mountains thus sink in ruin, and the violent and sudden shock is spread far and wide in terrible vibrations. Thus, a chariot, the weight of which is not very considerable, makes all the houses near it tremble as it passes, and the fiery steeds, drawing behind them the iron-armed wheels, shake all the places round. It might well happen that an enormous mass of earth should fall by reason of decay into some great subterranean lake, and that the globe should tremble in a series of undulations."

Caverns which are deserted by the rushing waters which formed them soon begin to be filled up again by a new agent. This agent is rain in which carbon dioxide is dissolved. It percolates down through the enormous filter of limestone above, and in so doing dissolves a small portion of the rock. The moisture, charged with calcium bicarbonate, evaporates, or parts with some of its free carbonic acid gas when it comes into contact with the air of the cave. The calcium carbonate, now no longer held in solution, precipitates and is set free on the arch of the sides of the cave, thus:

$$\underset{\text{Calcium Bicarbonate (Soluble)}}{CaCO_3.H_2CO_3} = \underset{\text{Calcium Carbonate}}{CaCO_3} + \underset{\text{Carbon Dioxide}}{CO_2} + \underset{\text{Water.}}{H_2O}$$

When a drop of water falls it leaves attached to the stone a small ring of the white calcium carbonate (chalk, limestone, marble). This is the commencement of a stalactite. Another drop of water trickles down, and, trembling on this ring,

FIG. 54.—Stalactite Columns.

Face page 262.

lengthens it slightly by adding to its edges another thin circular deposit of calcium carbonate, and then falls. Thus, drop following drop, minute by minute, day and night, summer and winter, for thousands of years, each drop depositing part of the dissolved calcium carbonate it contains, builds up a number of frail tubes round which the calcareous deposit slowly accumulates, until mighty pendants, which astonish us by their vast size and ornamental structure, hang downwards from the roof. The water which drops from the stalactites deposits some more calcium carbonate on the floor, and in the course of ages there rises up to meet the descending stalactite a corresponding column from the floor. Ultimately the two meet and slowly coalesce to form those mighty snow-white pillars which hold up and support the roofs of the most stupendous caverns. Indeed, there are few sights in the world more astonishing than that of these subterranean palaces, with their snow-white columns, their innumerable pendants and decorations, pure and glistening like Carrara marble. But in time the caves become entirely filled with these growths and cease to exist.

Often, though not always, stalactites grow extremely slowly. Inscriptions seventy or eighty years old appear covered only with a thin translucent coat. In the caves of Adelsberg names scratched on the walls more than six hundred years ago are still perfectly legible!

While regarding such colossal stalactites the mind cannot help being impressed with the innumerable procession of centuries required for their formation from trickling water; but even these time intervals appear quite insignificant when compared to the previous ages required for the hollowing out of solid rock of these vast underground cavities by the solvent action of running water. Still beyond these extend fathomless ages where the limestone rocks in which these caves occur were being slowly deposited in the depths of a long vanished primeval ocean, by the accumulation of the innumerable skeletons of tiny sea animals, which slowly grew, inch by inch, into layers hundreds upon hundreds of feet thick, and then were slowly forced upwards by gigantic earth movements until the bed of the sea became dry land.

Nor is this the end of the vast perspective. Glimpses of still more distant ages loom in the distance, and the mind grows giddy in plunging into the never-ending abyss of time and of realising epochs gone and forgotten, aeons before man or animals appeared upon the earth at all.

CHAPTER XII

SILICON AND ITS COMPOUNDS

EVERY one must have noted with a feeling of wonder, not unmixed with awe, the enormous mass of earth and rock which encompasses the globe on all sides. Beneath our feet lie miles of iron-hard rock, which extends downwards, layer after layer, mile after mile, until they reach the white hot regions of the interior and become merged in the mighty gleaming furnaces of the deep. In parts of the earth we find towering aloft, tier upon tier, in huge mountain ranges, millions upon millions of tons of rock and earth, which have been urged upwards into the air sometimes for several miles by mighty forces at play within the earth itself.

This stupendous display of matter has at all times awakened the curiosity of man. Very early in his history he strove to obtain some answer to the problem of its constitution. He appealed to his priests and wise men :

> " Read me the riddle of the show of things ;
> Dance of the seven stars, and stormy spray,
> Of mighty sunsets beyond mountain rings ;
> The sad level light of ebbing day along the corn."

But they could not answer him. Their guesses were wild and far from the mark. And no wonder ; for it took centuries of slow and patient labour ere man was in a position to attempt even to answer such questions. It was the chemist who first solved the problem of what earth and rock consist. Laboriously, step by step, with his balance and weights, with his tubes, beakers and filters, he toiled for hundreds of years upon this problem ; and ultimately he achieved success. He found that rocks, at least the oldest and most abundant kinds, are all compounds of one single element—the element silicon. They consist of this element

combined with oxygen, and metals like aluminium, iron, calcium, magnesium, sodium, potassium, and others, the whole forming a complex mixture of fused or chemically combined oxides. Yet silicon is the central element of the mass. It links together the other elementary atoms into those vast frameworks and chains of atoms which form and build up the gigantic skeleton of the earth's surface. No less than one quarter of the whole weight of the earth's crust consists of this element silicon. It is, therefore, in a combined condition, accumulated upon the earth in such huge masses that the mind cannot grasp their vastness; and we have every reason to believe that the same constitution must be attributed to the outer crust of the majority of the planets which exist in space. Indeed, it has been shown that in the case of our nearest neighbour, the moon, very probably the very same siliceous rocks which occur on the earth, also occur there. Thus M. Landerer found that the polarisation angle of the rocks forming the craters and abysses of the moon's surface coincided with that of certain siliceous rocks upon the earth, such as obsidian and vitrophyre. Again, meteorites which fly in from outer space upon the world almost invariably contain silicon, sometimes in such quantities as to make them almost identical in composition with the volcanic lavas which flow from out the earth's interior in volcanic eruptions. Moreover, the spectroscope reveals evidences of this element in the distant stars which are scattered through the deepest depths of space.

The element, therefore, is a universal one. It is not confined to our earth alone, but occurs in unthinkably vast quantities throughout the whole universe. Indeed, the quantity of silicon which occurs on this earth, huge as it seems to us, is but an infinitesimal portion of the total quantity which occurs even in realms which are accessible to our telescopes.

The substance, therefore, possesses a very considerable interest for us, and we shall devote this chapter to an examination of the element and its compounds.

Silicon belongs to the same family of elements as carbon, and like this element exists in several different modifications,

one of which—the crystalline—is hard enough to cut glass. Like carbon the element is extremely involatile and infusible. It requires the intense heat of the electric arc to boil, or even to fuse the substance.

Only one oxide of silicon is known. Chemists call it silica, and have shown that its formula is SiO_2. In other words, its molecules are composed of one atom of silicon united with two atoms of oxygen.

Even the most unscientific reader is acquainted with this substance, although, perhaps, all unknown to himself, for the common substances, sand, flint, rock crystal, agate, quartz, and opal, are more or less pure forms of silicon oxide.

Common sand, such as is found on the sea-shore, consists principally of tiny grains of silica. It is the debris of great masses of rock which once formed cliffs, bays, and headlands ages ago. Water acting on these rocks has in the course of time ground them down and washed from them all their soluble constituents, leaving behind the hard insoluble part, the silica grains, as dust upon the shore.

The amount of sand, either loose as sea-sand, or cemented together and consolidated by pressure into the hard rock known as sandstone, which occurs upon the earth is stupendous. Vast deserts of sand occur in Asia, Africa, Australia, and Arabia.*

Along every rocky coast, along the beds of oceans, and in rushing rivers we find it; but in still vaster quantities does it occur in a fossilised condition as sandstone. Let us mention, for instance, only one layer of it, well known to geologists, as it occurs in England alone, "the so-called New Red Sandstone, which, with its attendant marls, covers a vast tract—and that a rich and busy one—of England. From Hartlepool and the mouth of the Tees, down through Yorkshire and Nottinghamshire; over the manufacturing districts of central England; down the valley of the Severn; past Bristol and the Somersetshire flats to Torquay in South Devon; up north-westward through Shropshire and Cheshire; past Liverpool and northward through Lancashire;

* Not all of this sand, however, is silica, some of it being merely powdered soil like the dust of our high roads.

reappearing, again, north of the Lake Mountains, about Carlisle and the Scotch side of the Solway Firth, stretches the great New Red Sandstone plain, from under which everywhere the coal-bearing rocks rise as from a sea. . . . It is five thousand feet thick in places, and stretches not only across England, but also into Germany."*

Whence came this enormous mass of sand ?

It is the débris of rocks, thousand of feet thick, which have been worn down ages and ages ago by wind and water, and then were buried over by mud and earth, and finally, under the great pressure, have coalesced into the hard rock which makes such excellent building stone.

Sandstone, however, can undergo a further change. When these beds of sand sink slowly beneath the ground as they often have done in past times, until they reach the fire and heat of the internal regions, then a wonderful transformation takes place. The sandstone under the enormous temperature and pressure there prevailing is transformed into a fused homogeneous mass, which, later arising grandly and slowly for thousands of years as the result of the vast earth-movements which are ceaselessly taking place within the globe, again reaches the surface. But in how different a condition ! It went down a formless mass of sand, it comes up a beautiful white rock, the hard enduring quartz, of which whole mountain ranges are composed. Sometimes, so deeply has this quartz sunk into the bowels of the earth and been twisted and torn by plutonic agency, that it is found impregnated with gold from the depths ; and in South Africa and Australia great quartz beds are now mined for the glittering yellow metal. Next time my reader sees a bed of quartz, let him not pass it by without reflecting upon its strange history. Think ! this hard white rock may have been once, ages ago, just ordinary bright yellow sand gleaming on a sunlit shore, washed by wave and rippled by wind. Before this, at a still vaster interval in the awful abyss of time, it formed the body of some mighty bed of rock, plutonic in origin, from which the sand was slowly produced by the action of sea, wind, and rain. Even here its history does

* "Half Hours Underground," p. 246.

not end. A still remoter period dimly looms in the unfathomable past, when this same silica whirled in the tumult and roar of the elemental flame from which our world was born. Before this, no man can say how long ago, it formed part of the great sea of ether which surrounds us on all sides and through which

> "The earth itself alone
> Wheels through the light and the dark
> Onwards to meet the unknown."

The dead poet, John Davidson, once remarked of a famous London street:

> "Fleet Street was once a silence in the Ether,
> The carbon, iron, copper, silicon,
> Zinc, aluminium vapours, metalloids,
> Constituents of the skeleton and shell
> Of Fleet Street—of the woodwork, metalwork,
> Brickwork, electric apparatus, drains,
> And printing presses, conduits, pavement, road,—
> Were at first unelemented space,
> Imponderable tension in the dark
> Consummate matter of eternity."*

The same could be said with equal truth, of every particle of sand in the Universe! The common sand about us, therefore, is not uninteresting—if rightly viewed. Far from it. Each particle of silica, each piece of quartz, each flintstone, or gleaming opal, can tell a story more wildly grand and romantic than anything that you or I, dear reader, have ever thought of!

Now let us return again to our sand. It is said that a handful of sand from the African desert, when examined with a lens, is seen to be full of rounded grains. The wind, dashing the particles together for ages and ages, has caused their angles to be worn off, and each little particle has become converted into a miniature pebble. Sometimes these sands are driven by the wind in great masses over cultivated lands, turning them into deserts, and bringing ruin and destruction with them. This has happened in every part of the world at some time or other. What secrets, what peoples, and forgotten civilisations, lie buried under

* "Fleet Street and Other Poems," published by Grant Richards.

FIG. 55.—Spear-head.

sand can now only be conjectured. It is certain that sand now reigns supreme in districts where, even in historical times, once rich meadows, gardens, and glad pastures existed. Ruins of old and forgotten cities meet one on every side, buried under sand, in central Asia and Mesopotamia.

If silica in the form of sand has been one of man's most formidable enemies, there can be little doubt that silica in the form of flint stones has been one of his greatest friends. By means of flint stones he arose and gradually attained the mastery of the world. At some remote time man was an almost defenceless ape-like creature, far inferior in strength and agility to the huge and fierce animals which then swarmed all over the earth. He lived in terror of these monsters, hiding on tree-tops and in holes, like a wild animal. He fled before them much as mice flee before cats, or rabbits before dogs, and probably defended himself by hurling stones and branches of trees at them. One day some forgotten savage, a genius in his way, discovered that a fractured flint stone, if chipped to a suitable shape, made a most formidable weapon, cutting like broken glass or sharpened steel. Later, he increased the force of its blow by fastening it into a wooden handle, when it formed a serviceable axe or spear. Thus he gradually learnt not only to make formidable flint knives, but also axes, spears, and even arrows tipped with flint, which would kill animals far swifter and more powerful than himself. It was only at a comparatively recent period in the history of the human race that bronze and iron replaced the use of flint. Our illustrations show some flint weapons.

FIG. 56. Spear-head.

These were often beautifully worked and elegant in form.

As regards the origin of flint, it occurs in chalk beds, and appears in many cases to have replaced the chalk itself about a nucleus. When chalk is worn away by rain or water

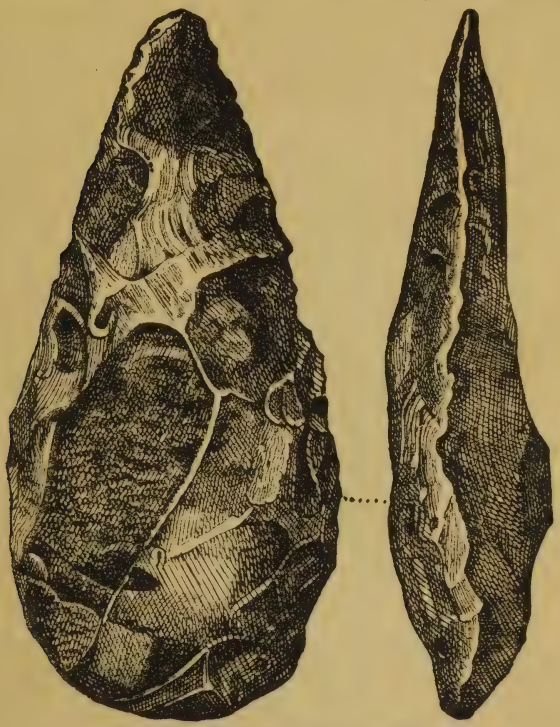


FIG. 57.—Spear-head, front and profile.

the flint stones in it remain behind, being much more durable. If a flint stone be broken open it will usually be found to have grown around a fossil by some slow process of aggregation.

Opals, those beautiful stones whose hidden fires, red, blue, and green, gleam forth from their depths, are nothing more than silica containing combined water. The stone bears

minute fissues, striated with microscopic lines, which diffract the light and flash out rainbow tints of pure and brilliant hues. Some thousands of years ago the opal was known and prized among the civilised peoples of the earth as a valuable jewel. We are told that the senator Nonius was banished by Mark Antony for the sake of a magnificent opal set in a ring and valued at £20,000 of our money. By presenting his jewel to the triumvir he might have escaped banishment. He preferred to withdraw with his jewel than stay in Rome without it.

One of the finest opals in the world belongs to the imperial jewels of Austria. It gleams magnificently with green and red flashes of light, and weighs no less than seventeen ounces. Half a million florins have been offered for it, but without success.

Very fine opals have been sold at prices which rival that asked for diamonds of equal size. Black opals also exist, and are highly valued. They allow the red fire of the ruby to flash out gorgeously against the darkness of the stone. Besides opals we get precious stones, such as amethyst, cairngorm, jaspers, and chalcedonies, which are also composed of silica, but which are, at the same time, coloured with a trace of some impurity, usually the oxide of a metal.

A description of all the varieties of silica used for ornamental purposes would occupy too much space, but this account would not be complete without a few words on rock crystal.

Many varieties of this beautiful mineral are found. For example, there is violet rock crystal or amethyst, yellow rock crystal or "false topaz," black rock crystal or "morion," and brown rock crystal or "smoke quartz." The beautiful limpid and colourless kinds are often called Bristol or Irish diamonds. They occur in the Alps, and, indeed, in all regions where a great deal of quartz rock is found. They are much used for making jewellery and optical instruments. The use of quartz instead of glass for lenses is especially valuable; for being harder than glass it will not easily scratch or lose its polish. Its use in spectroscopes depends upon the fact that it is extremely transparent

to ultraviolet light. The substance has other valuable properties, but we cannot discuss them here.

Small rock crystals have little value, but high prices are paid for large ones. Consequently they are much sought for by the chamois hunters and goatherders of the Alps. Nearly a century and a half ago a quartz cave was found at Zinken which gave twenty tons of beautiful rock crystal, which sold for over 300,000 dollars. One single crystal weighed 800 lbs. In 1867, some tourists, descending from the solitudes of the Galenstock, saw some dark spots in a band of white quartz which traversed the face of a mighty precipitous cliff. The guide, Peter Sulzer, of Guttannen, declared them to be cavities which would certainly contain rock crystal. No search was made at the time, but some weeks after Sulzer and his son revisited the place, and climbed up the perilous cliff until the holes were reached. They found that they led inwards into a dark cavity from which they took out some pieces of black rock crystal with the curved handles of their alpenstocks. Next year, accompanied by a few friends from Guttannen, to whom they had told the secret, they made a determined effort to force their way into the cave. Boldly they climbed the cliff and reached the cavity. Here they had to maintain themselves on a small ledge, only a few inches wide, overhanging a nearly vertical cliff, and at the same time use the hammer and other implements for breaking up the rock.

The weather was very bad. Every now and then a fierce gust of wind threatened to tear them from their clinging place and hurl them down upon the glacier deep below. Hail and rain stiffened their limbs, and to make matters worse, darkness came on and found them still at work. They passed a dreadful night closely huddled together on a narrow ledge before the cavity. At last morning broke and found them wet to the skin, with their teeth chattering with cold. They resumed their labours, and at length widened the entrance sufficiently to allow them to penetrate into a cave which plunged into the mountain for a considerable depth. It was filled nearly to its roof with a mound of fallen rock and sand; but here and there,

imbedded in the rubbish, gleamed jet-black morions, which showed that their toil had not been in vain. Originally the crystals had grown on the sides and roof. Here they must have hung for many thousands of years until, at some unknown time, the concussion of an earthquake, or perhaps their own weight, precipitated them with a crash upon the floor. More than a thousand large crystals were found in the cave, many of them weighing from fifty pounds to more than three hundredweight. The first explorers collected about a ton of crystals, and brought them to the village. In a short time the greatest excitement reigned here, and the whole able-bodied population of Guttannen, armed with hammers, spades, baskets, and ropes, poured out in a long stream to the cave, and began to carry away the remainder. Meanwhile, the report had spread that the Canton of Uri, on whose land the cave was situated, was about to stop their proceedings. So the men worked day and night with feverish haste, and in the space of a week had stripped it of its treasures. The stones were conveyed over the glaciers, and over the roads beyond the reach of the authorities.

FIG. 58.—Discovery of the Rock Crystal Cave of the Galenstock by the guide Peter Sulzer and his son in 1867.

One of the party fell into a crevice with a crystal of a hundred pounds upon his back. He managed to get out, but lost his prize in the depths. The seven finest specimens were bought for 8,000 francs by the Berne Museum, and are still exhibited as a magnificent group.

The largest crystal, called the "King," is thirty-two inches high and three feet in circumference, and weighs 255 pounds. Next comes the "Grandfather" of inferior height but superior girth, and weighs 276 pounds. Most of the other fine crystals were sold to various museums and private collections for six or seven francs a pound. So that Sulzer's discovery brought much wealth to the little village.

The oxy-hydrogen blowpipe flame has a temperature (2,000° C.) just over the melting point of silica. Consequently, quartz can be melted in this to a colourless glass-like mass, which can be made to boil in the electric furnace. This fused quartz forms a truly wonderful glass. Since the year 1900 colourless vessels, tubes, and other pieces of chemical apparatus have been manufactured, which look exactly like ordinary glass but have this astonishing property: they can be heated to a white heat and suddenly plunged under water. Glass under such circumstances would fly into a thousand fragments. These quartz vessels are, however, not affected in the least by such treatment! The reason of this is that this quartz glass has the lowest co-efficient of expansion for heat of any known substance, the mean co-efficient between O° C. and 1,000° C. being only 0.0000007. Consequently, when suddenly cooled, great internal strains, such as shatter suddenly cooled glass, are not set up. For the same reason the application of a sudden and intense heat to quartz vessels will not cause them to break. We all know, as a matter of painful experience, how easy it is to crack articles of ordinary glass by heating them too suddenly. For the chemist these articles are invaluable, because these quartz-glass vessels are inert to most operations; they may be heated hundreds of degrees higher than ordinary glass without melting, and, as we have already related, are extremely transparent to ultra-violet light. They are

at present, however, expensive articles, although doubtless the future progress of science will eliminate this disadvantage.

If quartz be melted in a blowpipe, and the end of an arrow be dipped into it and be suddenly shot off from a bow, the arrow flying through the air will draw out after it a long, extremely fine thread of quartz fibre ; such fibres, on account of their strength and fineness, are much used for suspending the moving parts of electrical measuring instruments. I suppose, too, that they could be woven into wonderful garments which would have the warmth and lustre of silk, combined with far greater strength and durability. Such silica cloth could be heated to a high temperature without damage, behaving in some respects something like asbestos. However, I have not heard of any experiments which have been made in this direction.

Silica, SiO_2, is under ordinary circumstances insoluble in water. Yet deep down in the earth water exists in a tremendously heated and compressed condition, and under such circumstances it acquires the power of dissolving silica from the rocks, forming silicic acid :

$$\underset{\text{Silica in Rocks}}{SiO_2} + \underset{\substack{\text{Compressed and}\\ \text{Heated Water}}}{2H_2O} = \underset{\text{Silicic Acid.}}{Si(OH)_4}$$

When such water comes to the surface where the pressure and temperature is low, it cannot hold so much silicic acid in solution. Consequently, some of it is deposited at the mouth of the spring, as a thick jelly, which afterwards passes into a hard white sinter. This especially occurs in volcanic regions. Many geysers are surrounded by mounds of silica. The most celebrated and perhaps the most beautiful of all these springs is the Great Geyser of Iceland. During the lapse of centuries this has formed for itself a base of silica no less than fifty-two feet in width, which serves as the wall of a funnel-like hole seventy-five feet deep, from the bottom of which rise the water and steam. When a discharge is to take place the water surface swells up in foamy heaps, and the ground trembles and roars with a stifled sound. Clouds of steam arise and shroud the basin. Suddenly an

enormous jet of steam and boiling water leap out with a mighty crash, and like a pillar of glittering snow shoots up 100 feet or more into the air. A second and a third jet rapidly follow. Then the water subsides in the basin, and for hours, sometimes for days, no fresh eruption takes place. Leaning over the edge of the hole, whence such a storm of foam and water has just issued, and looking at the tranquil blue surface of the water below, it is hard to believe in the sudden transformation that has taken place. The deposits of siliceous matter left by the spring have already erected a conical hillock around it, and sooner or later the increased pressure of the water thus enclosed will cause them to open a fresh outlet beyond the present one. But hot siliceous waters have produced even more wonderful effects in New Zealand. About the centre of the Northern Island thermal springs, mud-fountains, and geysers, rise in more than a thousand places. For a distance of more than a mile the lake of Tampo boils and smokes, heated by subterranean fires. A river runs from this lake down to the sea, and from its valley squirt so large a number of boiling water jets that in one spot alone seventy-six have been counted, rising to various heights, and playing alternately, as if governed by a mysterious rhythm in their successive appearances and disappearances.* Further on all is activity. "Liquid columns gleam all at once in the sun, and white cascades fall from terrace to terrace towards the river. Each instant the landscape changes, and fresh voices take a part in the marvellous concert of gushing springs."†

In this region once existed what has been termed the eighth wonder of the world, namely, the fairy Lake of Rotomahana. All around it bubbled and spouted hot siliceous springs. Eighty-two feet above the lake stood a deep crater-like basin, from the centre of which water and steam spouted out. The basin was composed of a dazzling white layer of silica which had been deposited by the clear waters which filled it. The water in this glittering basin was of a wonderful blue shade, rendered more beautiful by the reflection

* Reclus, "The Earth," p. 564.
† Von Hochstetter, "Neu Zeeland."

of rolling clouds of steam. The liquid overflowing from the basin ran into a similar pool, likewise covered with white silica, and falling thence from terrace to terrace reached the level of the lake. In this way a series of glittering steps of wondrous beauty and grace were formed, over which the water spread in thin sheets, and then fell in cascades. Sometimes the whole body of liquid in the upper basin was suddenly upheaved in a stupendous column with a roar like thunder, the whole presenting a scene of incomparable grandeur. Sad to relate, a volcanic eruption has within recent years swept away the whole fairy-like scene.

Similar terraces exist at the Mammoth Springs, Yellowstone Park, in the United States.

Two forms of silicic acid appear to exist: one, which dissolves in water to form a "colloidal" solution, something like a solution of glue or gelatine; the other is insoluble in water and forms a jelly.

When silica, SiO_2, is fused with caustic soda, NaOH, or better, with sodium carbonate, Na_2CO_3, an "Orthosilicate" of formula $Si(ONa)_4$ is formed. This looks like glass, and is soluble in water. For this reason it is called "water glass," and is used as a medium for preserving eggs, and for making artificial stone. If acid is added to the solution, orthosilicic acid is produced thus:

$$\underset{\text{Sodium Orthosilicate (Water Glass)}}{Si(ONa)_4} + \underset{\text{Hydrochloric Acid}}{4HCl} = \underset{\text{Orthosilicic Acid}}{Si(OH)_4} + \underset{\text{Salt}}{4NaCl}$$

The silicic acid remains in solution, and may be separated from the salt by placing the solution in a drum covered with parchment paper, and then floating the whole on water. The salt diffuses through the parchment, while the silicic acid remains behind. On evaporating the liquid in vacuo the solution of silicic acid is obtained as a viscid fluid, which, on raising the temperature, separates out as a jelly. This silica jelly is insoluble in water, and appears to have the constitution $O=Si(OH)_2$. It is termed "Metasilicic acid." On further drying water is gradually expelled, and finally

a mass is left which, on strongly heating, yields a white powder, which is pure silica or sand, SiO_2.

The innumerable carbon compounds which enter into the structure of living animals and plants are capable of forming similar jellies and colloidal solutions. Living matter, in fact, is of an essentially gelatinous nature. Perhaps this is one of the reasons why silica enters so largely into the constitution of some forms of living matter. Thus many plants, such as grasses, straws, bamboos, and other straw-like growths, store up in their harder parts quite large amounts of silica, which makes them stiff and hard and able to stand upright. They nourish themselves by means of the roots with solutions containing dissolved silica, and this is how the substance gets into them. Sea animals and plants are especially prone to assimilate silica.

Many of the lower organisms which exist in the ocean take silica out from the finely suspended clay floating in the water, and from it build up their skeletons. Tiny diatoms have formed in some parts of the world, by the slow accumulation of their siliceous skeletons, beds of "tripoli" or "polishing earth" or "kieselguhr," which within recent years have been much used in manufacturing dynamite. A truly wonderful structure these minute skeletons have, as the merest glance through a microscope will show. Other siliceous organisms are tiny animals called "Radiolaria." These creatures build up chambered structures of silica, sometimes of singular beauty and complexity. Some sponges also secrete considerable quantities of silica in the form of spicules; of these the beautiful Venus's Flower Basket is a notable example.

At some hot springs (especially in the geyser district of the Yellowstone Park in America) extensive deposits of silica are said to be caused by vegetation—principally algae—which possess the power of causing silicic acid dissolved in water to be thrown down as a stiff gelatinous substance in many varied forms. On the death of the plant the jelly-like mass, which consists of the siliceous filaments of the algae, and their slimy envelope, loses part of its water, becomes cheese-like in consistency, and finally hardens into stone.

We thus see that silicon—like the element carbon of the same chemical group—can enter into the constitution of living matter. Indeed, in past ages, when the seas were hotter and more closely in contact with the hot siliceous rocks, it probably played a much greater part in living matter than it does to-day. So also, for the matter of that, may sulphur, arsenic, phosphorus, and other elements which now occur in protoplasm only in the most trivial traces. Probably the structure of living matter has, like all other things we are acquainted with—for example, the atmosphere—undergone a continuous process of evolution (and is still undergoing it) with the changing external conditions.*

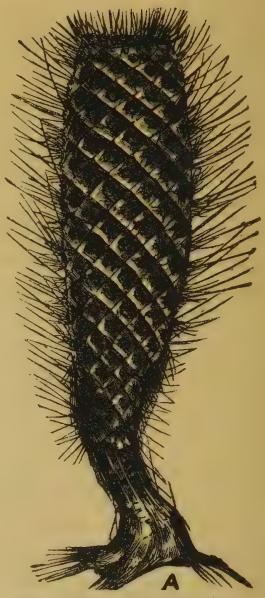


FIG. 60.—Euplectella Suberea Sponge. Many sea organisms take up silica from the sea-water and with it build themselves wonderful skeletons.

We have already mentioned that the primitive rocks are for the most part mixtures of complex compounds termed "silicates," which are unions of silica with metallic oxides. Mr. F. W. Clark, from the mean of 830 analyses of typical samples from the older or primitive part of the earth, deduced the following as its average composition: †

* The whole problem is fully discussed in the author's work "Researches on the Affinities of the Elements," in which it is shown that out of the four elements, carbon, nitrogen, oxygen, and hydrogen, which principally enter into the constitution of living matter, no single one is chemically differentiated by any properties from other elements. Every property possessed by them is shared to a greater or less extent by other elements as well. Consequently these other elements could presumably under other conditions replace them in living matter, and thus generate living forms which perhaps could flourish at quite high temperatures.

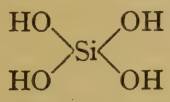
† "Geikie's Geology," p. 87.

Silica (SiO_2)	59.71
Alumina (Al_2O_3)	15.41
Ferric oxide (Fe_2O_3)	2.63
Ferrous oxide (FeO)	3.52
Lime (CaO)	4.90
Magnesia (MgO)	4.36
Potash (K_2O)	2.80
Soda (Na_2O)	3.55
Water (H_2O)	1.52
Titanic acid (TiO_2)	0.60
Phosphoric acid (P_2O_5)	0.22
	99.22

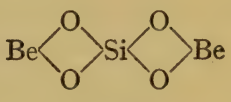
Nevertheless, the different minerals which go to compose these rocks vary somewhat widely in composition. According to Clark all the silicates may be classed as salts of five silicic acids, viz. :

$Si(OH)_4$	$OSi(OH)_2$	$H_6Si_2O_7$	$H_2Si_2O_5$	$H_4Si_3O_8$
Orthosilicic Acid	Metasilicic Acid	Diorthosilicic Acid	Dimetasilicic Acid	Trisilicic Acid.

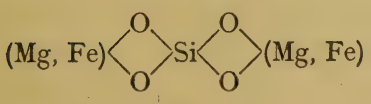
The subject is, however, much too complex to be discussed in a work of a popular nature. We may, however, give the formulæ which have been proposed for some naturally occurring minerals :



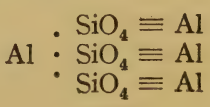
Orthosilicic Acid.



Beryl.

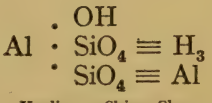


Olivine.

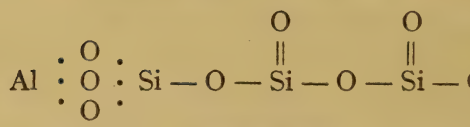


Xenolite.

Potash Mica or Muscovite.



Kaolin or China Clay.



Orthoclase Felspar.

However, since the molecular weights of these minerals are not known with certainty, their true constitution may, indeed, be very different from that given above. Indeed, some of the natural silicates appear so complex that no simple formula at all can be given to them. Although hardly anything is known of their true internal constitution, the reader must not come to the conclusion that the subject is dry and uninteresting. Far from it; for we are here on the verge of a mysterious unknown chemical world, which science has at present no methods of attacking and penetrating. We can truly believe, however, that, when in the coming centuries men have succeeded in devising methods for penetrating it, discoveries as wonderful and astonishing will be made in this realm of silicon compounds as anything appertaining to that of the carbon compounds, whose spread and development forms a veritable romance in the history of the nineteenth century. We may come to regard the seemingly inert rocks around us as the scene of changes as complex and wonderful as anything now going on in organic nature in such abundance. Certainly the microscope reveals in these rocks a very wonderful structure. How very remarkable, for example, are the structures revealed in the accompanying photographs of real rocks as seen through the microscope. These show us that the rocks are, indeed, far from the formless shapeless masses that they are commonly supposed to be among non-scientific readers. Some of them are full of tiny holes filled with liquid gas, often enclosing tiny crystals. Others are filled with invisible cavities and passages. We may, indeed, well ask: if in their coarse physical features the siliceous rocks reveal such a wonderful complexity of structure, what wonders would be revealed in them if we could only penetrate down to the minute atomic world below, and see the motions and groupings of their tiny

molecules, and the long chains of vibrating atoms which compose them? Were we endowed with senses a million times more delicate than those we possess the silent rocks would surely awake and emit the thunder of countless billions of atoms clashing, rushing, swinging ceaselessly. We should perceive the rocks to be the seat of vast forces, whose very magnitude would appal and amaze us. All notion of their inertness would vanish with our ignorance. The phrase

FIG. 61.—Wonderful Microscopic Structure of Siliceous Rocks. Many of these rocks are aggregations of crystals of different sizes, sometimes beautifully coloured. Besides these crystals millions of tiny cavities occur, often filled with liquids and containing still minuter crystals.

(Illustration from "Geikie's Textbook of Geology," Vol. I., p. 151, Figs. 14 and 15. Published by Macmillan & Co. in 1903. Fourth Edition.)

"dead as a stone" would become meaningless, for we should see that all rocks, all stones, are the theatres of mighty cosmic processes, scarce dreamt of by us, ceaselessly going forward night and day, summer and winter, for century after century, on a stupendous scale, until the mighty results so abundant on every side are produced. The whole fabric of the world itself, from its outer surface to its deepest depths, is in a state of never ceasing flux.

Let us illustrate this by an example. Every one has seen great mountains of hard rock, towering aloft into the sky, motionless, firm, silent, as if placed there for all eternity. Yet this apparent stability and immobility is quite false. The mightiest masses of rock are slowly crumbling, and at last

will pass to dust. In time, the hardest granite cliffs soften, fall, and disappear. Basalt, one of the hardest of rocks, becomes in time comparatively soft, and like granite, loses all its strength and rigidity. In Cornwall and in the Channel Islands, as well as in many other parts of the world, the granite has become so soft and rotten that it can be dug with a spade to the depth of several yards. If we go to the geologists they can tell of rocks thousands upon thousands of feet thick, piled tier upon tier aloft for miles, which have in time rotted and been washed into the sea. They can furnish you with examples of "denudation," as they call the process, which at first sight take our breath away, and cause us to ask: Is it possible? Is it credible? Hear, for example, what the geologists say regarding Snowdon: *

"Any one who saw that noble peak of Snowdon . . . leaping high into the air, dominating all the country round, at least upon three sides, would have the right at first sight, on hearing of earthquake faults and upheavals, to say the peak of Snowdon has been upheaved to its present height above and out of the lower lands around. But when he came to examine sections, he would find his reasonable guess utterly wrong. Snowdon is no swelling up of the earth's crust. . . . Snowdon is a mere insignificant boss, left hanging on one slope of what was once an enormous trough, or valley, of strata far older than itself. By restoring these strata, in the direction of the angles, in which they crop out, and vanish at the surface, it is found that to the north-west—the direction of Menai Straits—they must have once risen to a height of at least six or seven thousand feet; and more, by restoring them, especially the ash-bed of Snowdon, towards the south-east—which can be done by the guidance of certain patches of it left on other hills—it is found that south of Ffestiniog . . . the south side of the trough must have sloped to a height of from fifteen to twenty thousand feet. . . . The fact is certain, that off the surface of Wales, south of Ffestiniog, a mass of solid rock as high as the Andes has been worn down and carried bodily away . . . . If I am asked whither is all that enormous mass of rock—millions of tons—gone? Where is it now? I know not. But if I dared to hazard a guess, I should say it went to make the New Red Sandstones of England."

This is the epitome of the process. First hard rock which, when exposed to the air, changes on its surface; then a process of dry rot or decay sets in and renders its outer parts soft; then it crumbles and is washed away down into the

* "Half Hours Underground," p. 273.

valleys below by the rain and running waters, and this goes on year after year until all is washed away.

What is the reason ? let me explain, starting at the very beginning. You must all know that the rocks, at least the primitive ones, are but the frozen remains of a vast sea of liquid white-hot siliceous matter. Ages ago the world hung in space a liquid white-hot globule, surrounded on all sides with clouds of steam and rushing gas. It was at this period that the immense masses of siliceous rocks which now cover the earth were formed. Consequently their composition corresponds to chemical repose or equilibrium at a white heat. The carbon dioxide gas now stored up in the earth, then, as we have seen, floated free in the atmosphere, over this sea of white-hot molten siliceous rock. It could do this under such conditions ; but it cannot rest thus at lower temperatures. At lower temperatures the system is not in a state of chemical repose or equilibrium, for although at a white heat silica will decompose carbonates and drive out their carbon dioxide into the air, yet at ordinary temperatures the reverse is the change which takes place. The carbon dioxide will slowly decompose silicates, setting free silica or sand, and forming carbonates. The rocks, therefore, are not at ordinary temperatures in a state of chemical equilibrium with the carbon dioxide of the air, but are continually, century by century, absorbing it and decomposing. Hence, on a mighty scale there is continually going forward a change in the composition of the earth's crust. More and more carbon in the form of calcium and magnesium carbonate is being heaped up in the interior of the earth, while the silicon oxide which previously was combined with those metals is being steadily set free in the form of sand and clay. We may express the whole transformation, qualitatively, by means of the following scheme :

$$\underset{\text{Approximate Composition of Primitive Rock}}{Fe_2O_3.\ MgO.\ CaO.\ Al_2O_3.\ 10SiO_2} + \underset{\text{Carbon Dioxide}}{2CO_2} = \underset{\text{Calcium Carbonate.}}{CaCO_3}$$

$$+ \underset{\text{Magnesium Carbonate}}{MgCO_3} + \underset{\text{Clay}}{Al_2O_3.\ 2SiO_2} + \underset{\text{Sand}}{8SiO_2} + \underset{\text{Iron Oxide.}}{Fe_2O_3}$$

In consequence of the gigantic geological changes which have been going on steadily for almost unthinkably vast intervals of time, the large amounts of carbon dioxide which once floated in the air are now almost all withdrawn into the earth and stored up in the limestones and dolomites in the form of calcium and magnesium carbonates. Once the amount of carbon dioxide which floated in the atmosphere occupied a volume more than 800 times the whole volume of the present atmosphere. Now, in consequence of these geological changes, it is reduced to the minute percentage of 0.03. That is only three parts in ten thousand of air! Professor Ostwald believes that in the course of time every scrap of carbon dioxide will be withdrawn from the atmosphere, and that there will then not be enough of this gas to supply all the carbon of the living world, as it does at present, and that consequently living matter will have to alter its composition or perish. This time, however, is very far distant. At the present time very probably volcanoes alone throw more carbon dioxide yearly into the air than is taken up by rocks. We discussed this point in our chapter on carbon dioxide. We can, however, forcibly realise to what extent this gas is stored up in the ground by supposing that some awful giant from some other star were to soak the whole earth with a strong acid, such as nitric or hydrochloric, then this acid acting upon the limestones and carbonates of the earth would set free all the carbon dioxide stored up in the chalk with violent effervescence, and the gas would come pouring out of the ground in such quantities as to blow whole continents into the air and form a layer of gas around the earth some 700 or 800 times the present volume of the atmosphere. Indeed, the carbon dioxide thus evolved would exert such a pressure that under its own weight it would liquefy and form regular seas!

Silica at a high temperature also acts as a strong acid, and the same effect as regards the evolution of carbon dioxide would be produced by merely heating the earth to a white heat. The silica would then completely decompose the carbonates, evolving the gas, and restoring the earth to its ancient state. Perhaps, indeed, the carbon dioxide now

evolved in such quantities through volcanoes takes its origin in this way.

Without the aid of water, however, the carbon dioxide could never have effected these mighty changes. To water no rock is perfectly impervious. By it, probably, none are wholly unaffected. Water, especially when it contains carbonic acid dissolved in it, soaks into the rocks, dissolves out their soluble parts, and leaves behind the insoluble. The most insoluble constituent of most rocks is silica, SiO_2. Another very insoluble constituent is aluminium silicate or clay, $Al_2O_3.2SiO_2.2H_2O$. Still a third insoluble constituent is magnesium silicate or serpentine, $MgO.SiO_2.H_2O$. Hence, when water and carbon dioxide have acted for ages on rocks, we find that all their material is dissolved away and washed into the sea except these insoluble residues which are left behind. This explains the common occurrence of sand and clay all over the world in almost every region. It explains, too, why vast masses of serpentine rocks are found in certain parts of the world. They represent all that is left of still older rocks. The fine china clay or Kaolin is caused by the decomposition of granite rocks, and especially felspar, thus:

$$\underset{\text{Felspar}}{K_2O.Al_2O_3.6SiO_2} + \underset{\substack{\text{Carbon}\\\text{Dioxide}}}{CO_2} = \underset{\substack{\text{Potassium}\\\text{Carbonate.}}}{K_2CO_3} +$$

$$\underset{\substack{\text{Kaolin or China}\\\text{Clay}}}{Al_2O_3\ 2SiO_2} + \underset{\text{Sand.}}{4SiO2}$$

The clay is washed away from the sand and forms in beds. Ages later the clay thus formed consolidates to slates and other clayey rocks.

Thus we see how chemical science not only underlies the science of geology, but the study of a single one of its elements, the element silicon, introduces us to some of the mightiest geological problems that have ever exercised the human mind.

Glass and Pottery are the earliest products of man's chemical industry.

More than 6,000 years ago the plains of Mesopotamia were

covered with great cities built of brick and paved with asphalt. The capital of the Asiatic world, the wonder-city of Babylon, covered an area of nearly 200 square miles, and was surrounded by huge brick walls 342 feet high and ninety feet thick! In its centre towered mighty brick temples nearly 600 feet into the air. Even to-day the ruins of such structures, the Birs Nimroud, and the Babil, are 235 and 130 feet high respectively. We may well ask what European monument is there which, after crumbling in upon itself, would reach 130 feet after thirty centuries of ruin? Similar buildings existed at as early a period in Egypt.

Besides brick, earthenware vessels and beautifully coloured tiles were manufactured thousands of years ago both by the Egyptians and the Babylonians. Glass, too, was known probably 6,000 years ago. The temple of Belus in Egypt, a giant structure 600 feet high, was built sixty centuries ago out of bricks coloured with glass enamel. The invention of glass itself must have followed soon after. We find sculptures of glass blowers on the reliefs of the tomb of the king, Beni-Hassan, who lived 1800 years before Christ. In 1700 B.C. we find beautiful blue and white glass vases. We know that Sesostris, in the year 1643 B.C., had cast a monument of green glass. In later times the seat of the old glass industry was Alexandria and the towns Tyre and Sidon. Here, centuries before our era, gleamed and glowed great glass furnaces, while glass merchants grew wealthy and built themselves houses and palaces. All this, however, has long passed away; Tyre and Sidon are now marked only by a few ruins rising among the wretched huts of villagers. Alexandria still remains, however, a centre of commercial industry.

From the East the knowledge of glass and earthenware passed to Greece and Rome, and thence spread with the Roman legions all over Europe.

The modern glass industry is enormous. In the United States alone over 160,000,000 glass bottles are made yearly, besides vast amounts of window glass, glass globlets, pitchers, and ornaments. In Europe even greater quantities are made.

The primary materials for making glass are: Sand or silica (SiO_2); lime (CaO), lead oxide, or baryta; sodium carbonate (Na_2CO_3), or potassium carbonate, or sodium sulphate.

These materials are mixed together in the proportions suitable for the kind of glass required to be made—for there are very many different kinds of glass—and are then fused in a furnace.

Sometimes there are added to the glass for special purposes small amounts of oxides of metals, such as cobalt, copper, iron, tin, zinc, etc., as well as other stuffs, such as borates, nitrates, phosphates, carbon, etc.

Glass, in fact, is a complex mixture of silicates, to which no simple chemical formula can be given.

Glass may be coloured beautifully red by adding cuprous oxide or gold to it. Manganese oxide colours it red or violet. Cobalt oxide gives it a wonderful blue colour, and was used for this purpose thousands of years ago by the ancient Egyptians. The addition of lead oxide gives it a brilliance like diamond, and such "paste" is now largely used for imitation jewellery.

The reader should visit a large glass manufactory and see glass in the making. Here he will see huge furnaces with their glowing lakes of molten glass; and wonderful mechanisms for pressing the glass with ceaseless celerity into a multitude of different objects, such as jampots, saltcellars, vases, and other things as well.

Then there are the mixing machines, and a machine for picking up the glass, blowing it into a bottle, and dropping it into a receiver at the rate of six hundred an hour!

That the clay on a river's bank retained foot impressions, etc., which in the sun soon hardened and retained their form, must have been observed by the most primitive peoples. They formed, therefore, rude vessels out of this river clay and dried them in the sun; but since such sun-dried vessels soon fell to pieces when moistened with water, the great advance was made of heating them afterwards in a furnace. Under such treatment they hardened and retained their form when brought into contact with water. As we have seen already, pure clay is a silicate of aluminium, whose

formula is $Al_2O_3.2SiO_2.2H_2O$. Impure clays vary considerably in composition, usually containing much iron oxide, which gives them their dark red colour, as well as free silica, magnesium, and calcium carbonates. Plastic clays will take up 78 per cent. of water and form a dough-like mass, which can be squeezed or worked into any form we wish. When small quantities of oxides of different metals are added to the clay and the whole strongly heated in a furnace it hardens to our ordinary earthenware. The addition of quartz or felspar to pure white clay cements it on intense heating into white porcelain.

CHAPTER XIII

SULPHUR AND ITS COMPOUNDS

THE familiar yellow sulphur is an element which is very widely distributed. In every volcanic region of the earth we find sulphurous exhalations arising, especially from craters and solfataros, which impregnate the earth around them with this element, although seldom in quantities large enough to be remunerative. Very large amounts of sulphur occur in Sicily, where the element has been mined for centuries. The numerous sulphur pits of that island are situated chiefly in the southern districts over an area of 150 geographical miles. They occur in crevices and hollows, where the sulphur is, no doubt, the product of volcanic actions which took place in tertiary times. In such districts, rising up through countless clefts and fumaroles from the mysterious furnaces of the deep, we find the poisonous gases hydrogen sulphide, H_2S (sulphuretted hydrogen), and sulphur dioxide, SO_2. Mingling together, they mutually decompose each other, producing sulphur, thus :

$$\underset{\text{Hydrogen Sulphide}}{2H_2S} + \underset{\text{Sulphur Dioxide}}{SO_2} = \underset{\text{Sulphur}}{3S} + \underset{\text{Water.}}{2H_2O}$$

The oxygen of the air also decomposes the sulphuretted hydrogen slowly, thus :

$$\underset{\text{Hydrogen Sulphide}}{2H_2S} + \underset{\text{Oxygen}}{O_2} = \underset{\text{Sulphur}}{2S} + \underset{\text{Water.}}{2H_2O}$$

As a result of such actions the liberated sulphur condenses in the gypsum and clay grounds of the superficial strata. Some authorities believe, however, that it is produced in part directly from the gypsum ($CaSO_4$) as the result of bacterial action.

Formerly, when sulphur was used solely for making gunpowder, its production was relatively insignificant; but at the present time it is used for a great many other purposes —such as making sulphuric acid, bleaching, as a disinfectant, for making vulcanite, mosaic gold, and other commodities —and consequently its price has risen considerably, being now practically the chief article of Sicilian exportation. Girgenti is the most important sulphur exporting town in South Sicily; yet its dirty miserable streets and its 19,000 inhabitants form a sad contrast to the wealth and luxury of ancient Agrigentum, within whose lofty walls a population of 800,000 once lived. All the neighbouring sulphur pits send their produce to the port of Girgenti, and on all the roads one meets with long files of mules and asses loaded with sacks of sulphur.

It was the grape disease—against which sulphur was found to be the only effective remedy—that gave a new impulse to the sulphur industry by raising the price to about three times its old value. As soon as the grape disease became a national calamity for the chief wine-producing countries, the merchants of Girgenti at once bought up large tracts of sulphur lands and thus made their fortunes.

In order to extract the element from the sulphur-rich earth the Sicilians now burn it in circular kilns about thirty feet in diameter and ten feet high. First of all straw is introduced; then on this are laid large blocks of sulphur-rich earth, with air spaces between; over this come smaller stones, and finally the top is covered with a layer of the burnt-out earth from former operations. On lighting the straw the sulphur in the lower layer of stone burns and the heat thus generated melts out the sulphur in the earth above. It pours down and collects as a yellow compact mass in a receptacle under the kiln. The product thus obtained is very impure, and it is now usually purified by distilling from large iron retorts into brickwork chambers. Here it condenses as a light yellow powder sold as "Flowers of Sulphur." After a time the chamber becomes heated and the sulphur then collects as a liquid, which is drawn off and cast into

conical wooden moulds, and is known as roll sulphur or brimstone.

The sulphur earth usually contains thirteen to thirty per cent. of sulphur and occurs in great beds fifteen to ninety feet thick. Some of the longest excavations in them are so narrow that a man can only with difficulty pass; then they expand into high vaults, whose roofs gleam and glisten with beautiful crystals of celestine and gypsum. An oppressive heat reigns in these pits, and the workmen are on this account quite naked. Their dark skins, sprinkled with dirt and yellow sulphur dust, give them a strange and savage appearance.

The majority of the people of Girgenti work in the sulphur pits; a few are engaged in cultivating the beautiful gardens and fields which roll from the foot of the town to the sea, and cover the site where once the busy streets and stately palaces of the ancient city of Agrigentum rose from the shore to the terraced hills above, which are still crowned with the ruins of her colossal temples. Sicily yields yearly nearly 100,000 tons of sulphur.

Perhaps the most remarkable event in the history of the Sicilian sulphur fields occurred in 1787 in the celebrated pit of Sommatino, which is situated on the precipitous right bank of the Salso Valley. Some workmen accidentally set it alight, and the fire raged incessantly for two years, filling the pit with deadly sulphur dioxide gas and causing the complete abandonment of the mine. The owners gave up their property as lost and seemed menaced with utter ruin; but one day, quite suddenly, the mountain side burst asunder, dense fumes and yellow smoke poured out of the falling earth, and from the midst of it a mighty stream of molten sulphur rushed forth and buried itself in the neighbouring river. This phenomenon was caused by Nature performing on an immense scale an operation similar to that by which sulphur is extracted from the ore. The heat of the burning sulphur in the mine melted it in the rock above and caused the liquid to collect in the cavities of the mountain side to such an extent that this split asunder, and a mass of pure sulphur, amounting to more than 40,000 tons, was cast forth. By

this lucky event the owners of the pit were suddenly raised from threatened ruin to a condition of affluence.

Italy also yields a very large amount of sulphur. In 1900 no less than 400,000 tons of sulphur were obtained from her mines. Enormous beds of sulphur occur in the United States of America. Quite recently these have begun to be worked by a new process with very great success. The sulphur is melted out by means of superheated steam, and the molten sulphur is then pumped up from wells to the surface.

Remote Japan—that region of earthquakes and volcanoes —has within recent years entered the field as a sulphur supplying land; and, indeed, enormous supplies of sulphur, often in an almost pure state, are met with. Kämpfer in his "History of Japan" mentioned that it is the produce of a small island called "Iwogasima" or the "Sulphur Island." "It is not above a hundred years since the natives first ventured to explore that desert spot, which, from the smoke rising from its surface, was previously supposed to be the abode of demons. At length, a bold adventurer obtained leave to visit the dreaded island. He chose fifty resolute men to accompany him on his hazardous expedition, and on landing, instead of the fiends he expected to encounter, he found a volcanic soil, covered in many parts with thick deposits of sulphur, and emitting dense clouds of smoke from countless fumaroles. Ever since that time the island yields a considerable revenue to the Prince of Satzuma." An interesting account of sulphur mining in the Island of Etrofu, near Japan, has recently been given by Mr. Crawford.* He says, "On the upper end of a little island in the North Pacific Ocean, half way between the most northern point of the mainland of Japan and the Peninsula of Kamchatka . . . are located what are now supposed to be the most valuable deposits of sulphur in the world. There are three volcanic mountains, about 2,800 feet in height, of almost pure sulphur, and the vapours pouring from the summit of each are adding to the deposits day by day. The island is away from all the lines of regular communication, and so far north that

* *Cassier's Magazine*, November, 1900, April, 1901, Vol. 19, p. 311. Quoted by kind permission of the publisher.

FIG. 62.—Girgenti, in Sicily.

Although a small town of only 19,000 inhabitants, yet a large proportion of Sicilian sulphur is exported from it. In the foreground are seen the ruins of the ancient Agrigentium, which once held a population of 800,000 within its lofty walls.

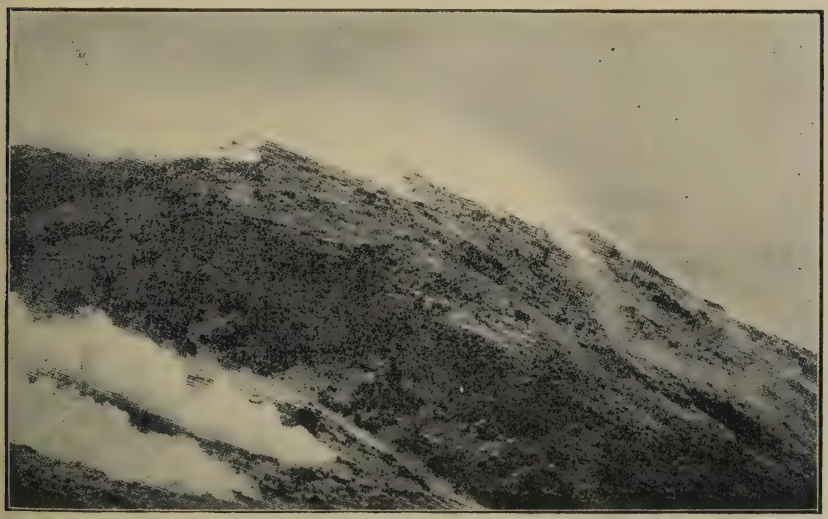


FIG. 63.—At the top of Sulphur Mountains near Japan, 2,800 feet above sea level.

Notice the suffocating gases and vapours rising up through the soil. The whole of the ground seen in the illustration is solid, almost pure, yellow sulphur, of unknown depth. (From *Cassier's Magazine*, Vol. 19.)

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it is completely ice-bound from November to May." In 1898 the island was explored by American and Japanese engineers, and it was discovered that the immense sulphur cones were located about two miles from the sea-coast, within easy reach of an excellent harbour called Moyors Bay. It is estimated that over 1,500,000 tons of almost pure sulphur are here lying on the ground, and this is now actively mined in the summer months (in winter the ground is covered with twenty-five feet of snow), and transferred to the bay by an overhead wire rope transmission plant. It seems almost incredible when we read of mountains of pure sulphur, which have only to be dug away like earth, and carted in a pure condition to industrial centres! Yet this seems to be the case here. "The writer's first view of the deposits," continues Mr. Crawford, "showed clouds of steam pouring from several places near the summits of the hills, and far down along the sides glistened immense patches of dull yellow, which were occasionally lost to sight as a fickle breeze wafted the vapours in such a way that the brighter yellow sulphur of the summit could be seen. . . . On climbing to the top, the hills were found to consist of almost pure sulphur, inasmuch as diggings at every conceivable place brought up the yellow crystals. The sulphurous vapours which poured from subterranean depths were suffocating, and, instead of issuing from only a few places as it seemed when viewed from a distance, the whole cap of each hill was honeycombed, and each outlet was continually adding to the stock, day by day, as the vapours were condensed." Naturally the sharp acid fumes in the air destroy the vegetation of the island, and it is practically an utterly barren waste, except along the shore.

Most minerals when once removed by mining operations are irreplaceable, and the deposit is thus gradually exhausted; but this is not so with sulphur. Very often the deposits are renewed again, and that within fairly short intervals of time. This is especially the case on the floors of the craters of partially extinguished volcanoes. Thus, to give one case, the mixture of sulphur and gravel on the floor of the old crater at Puzzuoli, near Naples, is dug up and distilled to extract sulphur. The gravel is then returned to its original place,

and in about thirty years is again so rich in sulphur as to serve for the same purpose once more!

Leopold von Buch states that: "The crater of the Peak of Teneriffe is now but an immense Solfatara. The sulphurous vapours which escape from every part of the vast cauldron, decomposing the rock, convert it into clay, and cover it in many places with beautiful crystals of sulphur. By this constant chemical action, the soil towards the centre of the crater has been rendered so soft that in many cases great caution is necessary to avoid sinking into the yielding mass, which has a temperature higher than that of boiling water." In Armenia the sulphur is precipitated in thick crusts on the vast inaccessible cliffs surrounding the volcano Alaghez. The people of the neighbourhood have a peculiar method of collecting this mineral. They fire at masses of it which cluster on the sides with musket balls and pick up the fragments thus detached!

In Java, near Patuka, is a circular lake over a quarter of a mile in diameter, surrounded with a luxuriant vegetation and filled with clear water of a bright yellow tint caused by the reflection of a vast sheet of sulphur which covers its bottom. In the lake occurs an island composed entirely of sulphur! It is well known that wonderful volcanic caves occur in various parts of the world. They have in most cases been formed by the passage of vast volumes of steam and vapour through red-hot molten rock. Thus a famous cave on Etna, the "Fossa della Palomba," consists of a series of dark cavities, penetrating downwards by a series of precipices, which are descended by ladders. The vaults terminate in a great gallery ninety feet long, beyond which lies still a passage never yet visited. The volcanic caves in the Island of St. Michael, in the Azores, are still vaster. Their entrance is through a narrow crack which expands suddenly into an enormous hall, whose distant roof is hidden in darkness even in the strongest torchlight. In one spot an opening in the floor shows that the lava, here but a foot thick, forms the roof of a huge cave underneath, into which even the boldest explorer has never yet ventured; but the noise of stones dropped into the abyss prove it to be of con-

siderable size. Other caves of great height open out from the first one. The famous Surt-shellier cave in Iceland is a similar cavity of vast extent. "It has been very appropriately named after Surt, the prince of darkness and fire of the ancient Scandinavian mythology; for this gloomy deity could not possibly have chosen a fitter residence than its vast and dismal halls, once glowing with subterranean fires, and now the seat of perpetual darkness."

Naturally, after what we have said about the occurrence of sulphur in volcanic districts, it will not surprise the reader when we tell him that many of these subterranean cavities are incrusted with sulphur and filled with poisonous sulphurous gases. Thus the mountain Büdöshegg in Transylvania possesses such caves. On advancing a few steps into one the air becomes sharp and suffocating, and the feet begin to feel a warmth which gradually increases to an intolerable heat. Still further on the lights are extinguished, and a speedy retirement is necessary. Imprudent explorers have been known to pay for their curiosity with their lives.

In the island of Milo likewise are sulphur caves which yield annually some 500 tons of pure sulphur. Still a visit is not without danger owing to the suffocating fumes which issue from crevices in their floors and sides.

Seldom, indeed, have such extraordinary efforts been made to collect sulphur above the regions of perpetual snow as were made by Cortez during that wonderful campaign which ended in the overthrow of the empire of Montezuma.* Being in want of powder he sent a body of men under Francisco Montano, a cavalier of resolute courage, to collect sulphur from the smoking throat of Popocatapetl, which towers, covered with a dazzling mantle of everlasting snow, to the height of 17,852 feet above the sea level. First they struggled through the lower regions, which were clothed with dense forests so thickly matted as to be almost impenetrable. Higher up they struck a black surface of glazed volcanic sand and lava, the overflow from some recent eruption. Its broken fragments, arrested in its boiling progress in a thousand fantastic forms, offered the greatest difficulties

* Prescott's "History of Mexico."

to their advance. Finally they came to the limit of perpetual snow, where fresh dangers presented themselves. The slippery ice gave them an insecure footing, and a false step might precipitate them into the frozen chasms that yawned around. Respiration became difficult in the thin air of these lofty regions ; every movement was attended with sharp pains in the head and limbs, accompanied with breathlessness. At last they reached the edge of the crater—a vast irregular ellipse more than a league in circumference. At the bottom a lurid flame burnt gloomily. From the depths rolled up clouds of sulphurous steam, which, cooling as it rose, condensed on the walls of the cavity. But who was to venture into the depths for sulphur ? All shrank from the awful risk. So lots were cast and it fell on Montano himself to descend in a basket into the terrible abyss. Down he went, with his frail vessel swinging in the air as he went, until he reached the depth of 400 feet. Here he found sulphur in abundance, and filling the basket he was hauled into safety again ; but it was not until the dangerous journey was repeated many times that the bold soldier had collected sulphur enough for the wants of the army.

The preceding cases show us that almost wherever we get volcanic action on a large scale, there we also find sulphur. The element is an almost constant concomitant of volcanic action. Judging from this one would certainly say that if we could, like the hero of one of Mr. Wells' novels, travel to the moon in a flying machine, we would certainly find there enormous deposits of sulphur, probably immensely exceeding any which occur on our earth. For the surface of the moon exhibits signs of having been in the past the theatre of the most tremendous volcanic action, compared to which the greatest displays which have occurred on our planet in historical times are absolutely insignificant. There our telescopes reveal to us the presence of mighty craters a hundred miles and more across, craters so vast that their huge precipitous walls, rising perpendicularly for thousands of feet, would actually be out of sight in the distance if we were standing in the middle of the crater floor ! Almost every square yard of our satellite's surface is pitted with extinct fumaroles and

FIG. 65.—In the Crater of Popocatapetl. This giant crater, which towers into the air to the height of nearly $3\frac{1}{2}$ miles, contains a large amount of sulphur. It was the source from which Cortez obtained the sulphur required for the gunpowder of the army which was to overthrow the empire of Montezuma.

(Illustration from "Land, Sea, and Sky," published by Ward, Lock & Co. in 1882.)

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volcanic openings, through which, doubtless, clouds of suffocating vapours once rose and deposited sulphur in every crack and cranny. No doubt, as in the case of terrestrial volcanoes, the walls of the mighty precipices surrounding these great craters are incrusted with sulphur, the undisturbed growth of ages, and in their centres the mounds and cones we see arising are perhaps impregnated with pure sulphur. Our telescopes, indeed, afford us indirect evidence of the presence of this element, for it is found that many parts of these volcanic beds are *snow-white*. It is believed that here the sulphurous vapours and steam arising up through them have decomposed the volcanic rock in much the same way that the same agents have decomposed the rock in the bed of the crater of Teneriffe, and have turned them into white beds of kaolin or china clay. A mineral prospector arriving from the earth would undoubtedly have a splendid time wandering about the silent mountains and dead valleys of our satellite and noting its mineral riches, which, in these airless and waterless deserts, have lain undisturbed and uncorroded for immense geological ages.

What we should see in these dead lunar craters may be surmised from what actually can be seen in active craters on the earth. Thus the crater of Vesuvius, as it appeared in 1867, is thus described by an eye-witness :—

> We stood on the summit (of Vesuvius) at last—it had taken an hour and fifteen minutes to make the trip. What we saw there was simply a circular crater—a circular ditch if you please—about two hundred feet deep, and four or five hundred feet wide, whose inner wall was about half a mile in circumference. In the centre of the great circus ring thus formed was a torn and ragged upheaval a hundred feet high, all snowed over with a sulphur crust of many a brilliant and beautiful colour, and the ditch enclosed this like the moat of a castle, or surrounded it as a little river does a little island, if the simile is better. The sulphur coating of that island was gaudy in the extreme—all mingled together in the richest confusion were red, blue, brown, black, yellow, white,—I do not know that there was a colour, or shade of a colour, or combination of colours, unrepresented—and when the sun burst through the morning mists and fired this tinted magnificence, it topped imperial Vesuvius like a jewelled crown. The crater itself—the ditch—was not so variegated in colouring, but yet in its softness, richness, and unpretentious elegance, it was more charming, more fascinating to the eye. . . .

Beautiful? One could stand and look down upon it for a week without getting tired of it. It had the semblance of a pleasant meadow, whose slender grasses and whose velvety mosses were frosted with a shining dust, and tinted with a pale green that deepened gradually to the darkest hue of the orange leaf, and deepened yet again into brown, then faded into orange, then into the brightest gold, and culminated in the delicate pink of a new-blown rose. Where portions of the meadow had sunk, and where other portions had been broken up like an ice-floe, the cavernous openings of the one, and the ragged, upturned edges exposed by the other, were hung with a lace-work of soft tinted crystals of sulphur, that changed their deformities into quaint shapes and figures that were full of grace and beauty. The walls of the ditch were brilliant with yellow banks of sulphur, and with lava and pumice stones of many colours."*

Magnify this picture a hundredfold, and you will obtain a good idea of the gorgeous scenery to be seen within the giant lunar craters, where there exists no rain nor air to dim the vivid colouring of the sublimed minerals. All remains as gorgeous and as fresh and as vivid as on the very day, millions of years ago, when they came up from the fiery deeps below, amidst torrents of choking and hot vapours.

The reader must not be led to suppose from what we have said in the preceding pages that free sulphur is solely the product of volcanic action, for it is also the product of the life-processes of certain curious bacteria which occur in innumerable millions in some waters and moist earths. These bacteria absorb so much sulphur that ten to twenty-five per cent. of their body is composed of this element. Some of them contain the sulphur in their bodies as tiny granules; from such bacteria vast quantities of sulphur have been deposited over different parts of Europe, especially in Urbino and Reggio in Italy, Radoboy in Croatia, and Girgenti in Sicily. In the same way that we acquire energy and warmth from the slow oxidation of carbon in our bodies to carbon dioxide, so do these strange creatures acquire their vital energy by the oxidation of sulphur to sulphuric acid.†

Sulphur occurs also in our own bodies, and in living matter generally—though naturally to a much smaller extent than in true sulphur organisms. The evil smelling gases given off

* "The Innocents Abroad," by Mark Twain.
† Professor W. O. Ostwald.

FIG. 65.—A Typical Landscape on the Moon.

Showing how the whole surface is pitted with vast volcanoes, some of which are fifty and more miles in diameter, and are surrounded by precipitous cliffs two miles high. Every square yard, almost, is pitted with craterlets and fumaroles in a way absolutely without parallel upon the earth. Since sulphur is almost invariably found in the neighbourhood of volcanoes, we must conclude that vast deposits of this mineral are to be found in the moon.
(Illustration from large photograph in James Nasmyth and James Carpenter's "The Moon," published by Mr. John Murray.)

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from a putrefying egg and from decaying animal matter are largely due to the evolution of gases rich in sulphur. Hair, wool, and the acids of the bile contain especially large quantities of it. The sulphur, however, appears to be but loosely combined in living matter, and its true function is unknown. It may be, however, that in earlier ages, and in the most primitive organisms, this element played a much more prominent part than it does now, and that the small quantities which now remain in ordinary living matter are the evolutionary relics of a time when it was far more abundant; for surely with the widely different thermal conditions which prevailed on the earth in early times the composition of living matter also must have been different, and its present composition is merely the end result of ages of evolution.

In the earth, too, sulphur is stored in enormous quantities, not free but combined with metals, forming compounds termed *sulphides*.

Ordinary sulphur is a yellow solid, insoluble in water, which melts at a low temperature (114-119° C.) and burns with a blue flame, emitting a poisonous suffocating gas called sulphur dioxide. It is this gas which causes the acid sharpness and suffocating properties of the air in volcanic crevices. Like carbon, the element sulphur exists in several different forms; for example there are two entirely different crystalline varieties known. These facts teach us that ordinary sulphur is not the simple substance that we at first sight imagined. It certainly has a molecule containing a large number of atoms, and it is the different types of molecules thus produced that give rise to the different modifications.

If sulphur is gradually heated it melts to a limpid, straw-yellow, mobile fluid. As the temperature rises the fluid thickens and darkens in colour, until at 180° C. it is almost black and so viscid that it can be scarcely poured out of the vessel. This is, indeed, a curious change, the cause of which is at present unknown. On heating to a still higher temperature the liquid becomes less viscid, and if it be then suddenly cooled by pouring into water we get another

surprise. The sulphur has changed into a dark coloured elastic mass utterly unlike ordinary sulphur. Indeed, it somewhat resembles indiarubber and can be drawn into long threads, which when released from tension spring back again. This modification is known as *plastic sulphur*. It is, however, unstable, for after a time it becomes hard and passes into ordinary yellow rhombic sulphur.

Very many important and interesting sulphur compounds are known, among which may be mentioned *sulphuretted hydrogen or hydrogen sulphide*, H_2S. This is a remarkable colourless gas which has a horrible odour similar to that of rotten eggs—which, indeed, owe their smell to it. The gas is colourless, very soluble in water, and burns with a faint blue flame.

Since the gas occurs as a product of the decay of animal matter it often accumulates in stagnant sewers and drains. Now the substance not only has a very evil smell, but it is horribly poisonous. No gas, with the possible exception of prussic acid vapour, kills with such alarming suddenness. A man entering an atmosphere of almost pure hydrogen sulphide suddenly and without any warning loses consciousness, and falls dead on the floor. Even when inhaled in small quantities it is rapidly fatal. Thus, 0.2 per cent. in the air kills animals in a minute or two, and 0.07 per cent. in an hour or two. Thus it comes about that workmen entering stagnant sewers have time after time been struck down by it and have lost their lives. A man has been known to descend into such a place and vanish. After a time the men above, hearing nothing of him, go down to see what has happened, reach a layer of the gas suddenly, and without even uttering a warning sound, fall senseless and perish. Indeed, the columns of our daily papers will often record sad cases where rescuer after rescuer has been struck down in this way.

In salt mines very often large amounts are evolved from the earth (probably by the action of acid waters on sulphides) and many fatalities have occurred. In volcanic regions the gas is often evolved from underground.

A very surprising outburst of hydrogen sulphide gas from underground occurred in 1896 during the building of Smith's

Point Lighthouse in Chesapeake Bay. While workmen were excavating the foundations of the lighthouse, working in compressed air in an iron caisson some fifteen feet below the level of the sea, the deadly gas suddenly began to stream into the workchamber from the sandy bottom of the sea.

Thirty-five men were in the caisson at the time. They smelt the horrible stench arisng from beneath them, and looking up, perceived that the candles stuck along the iron walls were burning with peculiar green flames. The gas began to work. Man after man began to stagger, giddy, with eyes almost blinded and a horrible burning sensation in the throat. A rush was made for safety, and all succeeded in escaping; but the men suffered terribly from the after effects; all night they lay sleepless and moaning, and in the morning only a very few could open their eyes at all, while light itself caused them the greatest pain. Bags were fitted over their heads, and they had to be led out to their meals. Meanwhile doctors arrived, and an examination of the caisson showed that the workmen had struck a vein of sulphuretted hydrogen gas. Indeed, when the air lock of the caisson was opened, the stench, even at a steamer's length from the caisson, became quite intolerable. For three days the force lay idle. Repeated attempts were made to rid the caisson of gas by flooding, but without success, and consequently all the work was at a standstill. On the fourth day the manager called for volunteers to go down the air shaft, and fourteen men bravely stepped forward " to see the work through," in spite of the appalling spectacle of thirty-five comrades moaning in their bunks, with blinded eyes and burning throats. Descending, they found the flow of gas much less rapid, and so they started working with feverish energy, expecting every moment to feel the gas gripping them. Every half-hour another shift of men came on, and by nightfall the lighthouse was within an inch or so of its final resting-place. The last shift had the worst experience of all. It was headed by an old caisson man, Griffin by name, a man of exceptional strength and endurance, who had borne the record air pressure of seventy-five pounds while sinking the famous Long Island

gas tunnel. It was well the men had this leader, for just as they were getting ready to leave the caisson the gas burst forth again with a roar from the sea-bottom, and in an instant filled the interior of the caisson. Then a terrible scene ensued. Flinging down their tools, all made a wild rush for safety; but the air shaft was narrow, and only one man could get up at a time. So they fought and struggled around the man-hole, pulling down by main force every man who succeeded in reaching the ladder rounds. Now the gas blinded them, and they began to stagger apart, swearing, praying, and beating with their naked fists on the iron walls, imploring to be let out. Finally the majority sank senseless upon the floor, only a few of the stronger ones escaping by scrambling up the ladder; Griffin remained below and signalled for a rope. At last it came down, and he groped for the nearest workman, fastened it round his waist, and sent him up. Painfully he collected the unconscious men beneath the air shaft, and when the rope came down again, sent them one after another aloft in the same way. Last of all came a powerfully built Irishman named Howard, and although Griffin was by this time half blinded by the gas and only semi-conscious, he managed to get him aloft. Now an unexpected difficulty occurred. The Irishman's body wedged fast in the eighteen-inch door of the air lock, and the men outside could not pull him through. So Griffin feebly and painfully climbed, as if in a bad dream, the thirty feet of ladder and pushed and pulled until the lifeless body went through. He attempted to follow, but his numbed fingers slipping on the steel rim, he slid back into the death-trap below, and relapsed into a semi-unconscious condition. The rope was lowered once more, and Griffin, rousing himself by a supreme mental effort from the torpor into which he was rapidly sinking under the influence of the gas, managed to fasten the rope under his arms, and was finally dragged up. Griffin was blind for six weeks, while two of the men had to go to a hospital and were months in recovering. Another man went insane, while four caisson men came out of the work with a painful malady known as "the bends," which often attacks those who work under great air-pressure.

The reader can easily prepare some of the gas and study its properties by merely pouring sulphuric acid on ferrous sulphide :

$$\underset{\text{Ferrous Sulphide}}{FeS} + \underset{\text{Sulphuric Acid}}{H_2SO_4} = \underset{\text{Ferrous Sulphate}}{FeSO_4} + \underset{\text{Sulphuretted Hydrogen,}}{H_2S}$$

Another interesting gaseous compound of sulphur is *sulphur dioxide*, SO_2. This also is colourless and invisible, with a strong sharp suffocating smell. Unlike sulphuretted hydrogen the gas will not burn, and extinguishes a burning light. It is very soluble in water, and the solution possesses bleaching properties. Goods like silk and straw, which would be damaged seriously by the application of bleaching powder, are often treated with the substance. The gas may be produced by heating strong sulphuric acid with copper in a flask, when it is evolved in a copious stream ; the reaction is complex but is usually represented by the equation :

$$\underset{\text{Copper}}{Cu} + \underset{\text{Sulphuric Acid}}{2H_2SO_4} = \underset{\text{Copper Sulphate}}{CuSO_4} + \underset{\text{Sulphur Dioxide}}{SO_2} + \underset{\text{Water.}}{2H_2O}$$

Sulphur dioxide is also produced when sulphur burns in the air, thus :

$$\underset{\text{Sulphur}}{S} + \underset{\text{Oxygen}}{O_2} = \underset{\text{Sulphur Dioxide.}}{SO_2}$$

As burning sulphur is used for disinfecting purposes, I suppose all my readers, even the non-chemical ones, have at some time or other smelt the peculiar suffocating odour of the gas when generated in this way. It is evolved in very large quantities from volcanoes, and is so heavy that it pours along the ground, like water, filling up hollows, and suffocating animals found in them. Even men have been overwhelmed by it when it pours from the top of the crater in eruptions. A well-known historical case is that of the elder Pliny, who was destroyed by the vapours which poured along the ground from the eruption of Vesuvius in A.D. 79, the same eruption that buried Pompeii and Herculaneum. Pliny was the admiral of the Roman fleet stationed at Misenum, and being informed that a great danger threatened

the inhabitants around the Bay of Naples, because Vesuvius, a previously inactive mountain, had broken into eruption, and was throwing out ashes and stones in every direction, he embarked with his ships of war and set sail to bring help to the people along the coast; but as he approached the coast hot ashes began to fall upon the ship, as well as pumice and other stones blackened and scorched by fire. Then suddenly the sea shoaled, and the masses ejected by the eruption rendered the coast inaccessible. The steersman advised him to sail back, but Pliny, animated with all the valour of a Roman gentleman, pushed onwards into danger, saying to the man, "Fortune favours the bold; steer towards the villa of Pomponianus." Here he landed, calmed his friends' fears, composedly dined and bathed—although the air was black with falling stones and ashes—and then retired to sleep. But now high columns of flame burst forth from Vesuvius, and lighted up the darkness and terrors of the night; the earth continually reeled and trembled, while the thunders of volcanic explosions reverberated around. Soon the ashes and stones were falling so thickly that the house was in danger of being buried, so waking Pliny, the whole party bound cushions upon their heads in order to protect themselves from the falling ashes and stones, and then with lighted torches in their hands they hurried to the shore in order to embark on the war-galleys. "Everywhere else day was shining, but here it was the blackest night, for the sun's rays were completely shut out by the falling dust and smoke clouds. But the sea was too wild and boisterous to embark. So Pliny lay down on a carpet and asked for cold water, which he repeatedly drank. But now there came rolling down from the mountains flames and black sulphurous vapours. All fled. Pliny rose, and leaning on two slaves, tried to walk, but immediately sank down again, suffocated by the dense smoke which rolled about him." Thus perished in his sixty-sixth year one of the greatest scientists and noblest characters of ancient Rome, the author of the first general description of the world. He undoubtedly succumbed to a mixture of sulphur dioxide and carbon dioxide gases which were pouring along the ground. If he had stood

FIG. 66.—Vesuvius.

In volcanic eruptions very large amounts of sulphur dioxide and carbon dioxide gases are evolved, which, being heavy, pour down the sides of the mountain like water. The elder Pliny lost his life, being overwhelmed in suffocating vapours which swept from Vesuvius in its first historic eruption in A.D. 79.

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the whole time like the rest of the party, and not lain on a carpet, there is little doubt that he would have escaped with his life.

Enormous volumes of sulphur dioxide and carbon dioxide were evolved during the great volcanic outburst in Iceland, in 1783. The ground split open, and such huge volumes of gas, accompanied by torrents of lava, were poured forth, that no less than 9,000 men, and over a quarter of a million of oxen, horses, and sheep were suffocated !

Sulphuric acid, H_2SO_4, also known as " oil of vitriol," is one of the best known and most valuable compounds of sulphur. It is manufactured on a large scale by oxidising sulphur dioxide.

CHAPTER XIV

THE PHOSPHORUS GROUP OF ELEMENTS

In the year 1674 the alchemist Brand, of Hamburg, made a remarkable discovery, which, a century and a half later, led to the development of a great industry employing many thousands of workmen all over the world, and put into the hand of every one the means of obtaining fire cheaply and easily. The story runs that he was heating in a retort evaporated urine and white sand in the hope of preparing a liquid supposed to have the power of turning silver into gold; while applying an intense heat he suddenly saw vapours arising from the retort and condensing on the cooler parts of the apparatus in the form of a waxy, translucent solid. On investigating this new body, which we now know is the element phosphorus, he found that it possessed the astonishing property of gleaming in the dark with a ghostly glimmer like pale moonlight, and when rubbed along a wall left behind it a luminous trail. Moreover, the substance was exceedingly inflammable. A very slight degree of heat—the warmth of the hand was sufficient—caused it to melt, catch fire, and blaze furiously, emitting dense white fumes. If the experimenter were unfortunate enough to get any of the blazing liquid on his skin, it inflicted dangerous and deep wounds, which often took months to heal.

Naturally the discovery of this strange element awakened a wonder and interest in the contemporary world very similar to that caused within our own times by the discovery of radium, and consequently it was possible for the chemist Krafft to make a tour of Europe and exhibit phosphorus as one of the wonders of Nature to various crowned heads. Among others our own King, Charles II., and the fair ladies of his court inspected it with lively astonishment. Even

after the lapse of more than two centuries, during which time phosphorus has changed from a substance almost as rare and costly as gold into a common and familiar body, we still view with wonder its cold gleaming light. Light without fire! Strange as the phenomenon seems it is but the outward manifestation of still more marvellous things. Think: in order to produce visible light, the tiny sub-atoms which build up the phosphorus atoms must whirl round their molecular orbits ten thousand billion times in a single second! "What an incredible speed!" my reader will exclaim; but I can assure him that this is going on continually, sometimes for months and years, so long as phosphorus gleams in the dark. Indeed we learn from optical science that even in the smallest particle of every material body, nay, even in what we deem empty space, there are colossal forces in perpetual action before which the ordinary energies known to us sink into absolute insignificance. Modern chemical research has made clear that the phosphorescence is due to a slow chemical combination. We must picture the phosphorus as giving off a vapour. Even as we watch it faintly gleaming we must imagine millions of its molecules pouring out from its surface into the air, and there colliding with the countless millions of oxygen atoms whirling and flying about in every direction. As the result of mutual collisions the two sets of atoms combine to form the white smoky luminous fumes which we see arising from all over the exposed surface of the phosphorus. The action is represented by the following equation:

$$\underset{\text{Phosphorus}}{P_4} + \underset{\text{Oxygen}}{3O_2} = \underset{\text{Phosphorus Oxide.}}{P_4O_6}$$

One of the most remarkable peculiarities of phosphorus is its ready inflamability. A piece if left out in the air gradually increases in temperature as the result of slow oxidation until at last it melts at 44.3° C. and immediately afterwards takes fire spontaneously at 45° C. The slightest degree of friction, especially contact with the warm fingers, will also cause it to inflame. Phosphorus, therefore, is a very dangerous substance, and in practice is always kept under water. This

ready inflammability of phosphorus naturally suggested an easy and certain way of obtaining fire, but the expense of the substance, which at that time ranged from ten to sixteen ducats the ounce, entirely prevented its general use for this purpose. It was not until Scheele (in 1771) showed that it could be obtained cheaply from bones that it was possible for any steps to be taken in this direction, and even then it was not until fifty years later that it began to be manufactured in quantity for the purpose in Paris. Bones, you must know, consist principally of a chemical combination of phosphorus with calcium and oxygen, called calcium phosphate, and having the formula $Ca_3(PO_4)_2$.

The phosphorus is now directly boiled out of them by heating this material, mixed with sand and charcoal, to a terrific temperature in an electric furnace, when the following reaction takes place:

$$\underset{\text{Calcium Phosphate}}{2Ca_3(PO_4)_2} + \underset{\text{Sand or Silica}}{6SiO_2} + \underset{\text{Carbon}}{10C} = \underset{\text{Phosphorus}}{P_4} + \underset{\text{Carbon Monoxide}}{10CO} + \underset{\text{Calcium Silicate.}}{6CaSiO_3}$$

Naturally when once the problem of supplying cheap phosphorus had been solved, it was not long before attempts were made to use it commercially for manufacturing matches. About 1833 this problem was successfully solved by a number of persons, and the famous lucifer matches began to be manufactured on a large scale. These consisted of splints of wood which were first dipped into a shallow pan containing molten paraffin, and then into another containing the igniting composition. This consisted essentially of finely divided phosphorus mixed with gum or glue, and combined with a quantity of potassium chlorate, red lead, or lead nitrate, in order to increase the combustibility, and then some colouring matter, such as cinnabar, smalt, or aniline dyes in order to make it attractive to the eye. The matches were then placed in a drying compartment, and remained there until the igniting tips were dry. Then they were taken out, counted, and packed into boxes. All this was done on the largest scale, a single factory sometimes turning out from six to ten million matches in a single day.

Every new substance possesses properties—sometimes of a most dangerous nature—which are often entirely unsuspected so long as the substance is employed only in the laboratory, and very occasionally at best even then, but which become known as the result of painful experience when it begins to be employed on the manufacturing scale. Phosphorus was no exception to the general rule. Its evil properties revealed themselves in a truly sensational manner. For the employment of phosphorus in match-making had not been introduced for a very long time before a terrible and mysterious disease, quite new to medical science, made its appearance among the workers. It commenced with toothache; the teeth decayed and fell out, and then the decay extended to the jaw and caused excruciating pain, from which the sufferer was relieved only by a surgical operation or by death. Here is the statement of one poor woman who worked in a match factory for five years and then contracted the disease. "My teeth began to ache, and then my top jaw. I did not take much notice of it till one day at the factory they gave me a paper to take to the doctor. He told me I was to go home and stop in my room till he saw me. When he came he said I must have four teeth out. That did not do any good. Then the pain got worse. Oh! it was awful. I thought I should go out of my mind with it. It was just as if somebody had got something scraping the bones in my cheek. And then he said that my husband and children must not be in the same room with me because the smell was so bad. The doctor went for his holidays, and while he was away lumps of my bone worked right out through my cheeks—it was festering dreadful. I kept the bone to show him. . . ." Naturally after this it will be understood that the suffering is terrible. Sometimes the disease eats away the roof of the mouth and the inside of the nose, sometimes extending upwards so that the sight is lost, together with the whole of the jaw-bone. Then the liver becomes enlarged and full of sores, and very often the patient dies after dreadful sufferings. This disease, which completely baffled medical science, was known to the workers as "phossy jaw," and to medical men as "necrosis." It appears to

have been brought about by inhaling phosphorus fumes. It raged in many factories and caused a great public outcry. Good ventilation and perfect cleanliness were found to do much towards diminishing the outbreak, but so long as ordinary phosphorus was employed, even in spite of all precautions, the disease, sooner or later, made its appearance.

The employment of ordinary phosphorus in matches had other serious disadvantages. They were luminous in the dark, liable to ignition on a warm mantelpiece, they absorbed moisture, and became useless with age. Still worse, since ordinary phosphorus is terribly poisonous many deaths occurred from children accidentally getting hold of these brightly coloured matches and sucking them. At the same time match-tops were used for the purpose of murder and suicide—especially on the Continent. Thus Dr. Blyth, writing in 1884, could even then state, "Phosphorus may be considered as the favourite poison, which the common people on the Continent employ for the purpose of self-destruction. It is an agent within the reach of any one who has two sous in his pocket wherewith to buy a box of matches, but to the educated, and to those who know the horrible and prolonged torture ensuing from a toxic dose of phosphorus, such a means of exit from life will never be favoured."*

The first symptom of phosphorus poisoning is a terrible feeling of pain in the stomach. Then follows vomiting of garlic-smelling substances, which are luminous in the dark. If the patient survives this stage, jaundice makes its appearance, and the patient dies in convulsions or sinks into a coma. Sometimes a new and terrible train of symptoms set in, in which the patient dies, sometimes after six days of agony, with blood oozing from eyes, nose, lungs, and bladder.

Naturally, all the Governments of the civilised world were soon in arms against this new scourge of civilisation. Some countries, such as Denmark and Switzerland, went even so far as to forbid the employment of ordinary phosphorus in match-tops at all. But a remedy was at hand. In 1845 the famous chemist von Schrotter discovered how to convert the yellow or ordinary phosphorus into a non-poisonous

* "Poisons, Their Effects and Detection," p. 199 (1884).

variety. It appears that one day he was heating ordinary phosphorus in a vessel out of contact with air to a temperature of between 240° C and 250° C, when he observed that after a time it solidified and changed into a hard red mass. This modification of phosphorus differed in an altogether extraordinary way from the ordinary yellow sort. Thus it gave off no fumes, had no smell, was not poisonous, and was not luminous in the dark. It was so hard to inflame that it could be heated to 260° C. before it took fire. At a higher temperature it was partially converted back into ordinary phosphorus.

Very soon attempts were made to replace the yellow phosphorus in matches by this red variety, and thus avoid all danger of poisoning. The matches made with it appeared excellent. They were not luminous in the dark, did not take fire on a warm mantelpiece, did not contract damp, and would keep for any length of time.

There was, however, a difficulty. When red phosphorus is brought into contact with potassium chlorate a slight touch is often sufficient to produce an explosion and blow the match-maker and his matches into the air. Many vain attempts were made to form a paste, and many accidents and some deaths occurred in consequence; but at length the happy idea occurred in 1855 to a Swedish manufacturer named Gundström not to attempt to make a paste at all with the red phosphorus, but to make the match lighter bring the essential ingredients together in the act of striking the match. Thus the famous Swedish safety match was born, which from Jönköping in Sweden spread throughout all the world.

In the ordinary match all the igniting composition is put on the splint, and the match can be ignited by friction on any rough surface. In the safety match, however, the composition is divided between the splint and the friction paper attached to the box. The composition put on the splints contains no phosphorus at all and is not poisonous. It consists of potassium chlorate, potassium bichromate, red lead, and antimony sulphide, while the friction paper is coated with a mixture of amorphous phosphorus and antimony sulphide.

The use of ordinary yellow phosphorus for friction matches has been forbidden in many countries, including England, and matches which strike on any dry surface are now largely made in which the so-called phosphorus sesquisulphide, P_4S_3, or Schenk's scarlet phosphorus, replaces the ordinary phosphorus. Such matches are less liable to accidental ignition and can be manufactured without serious poisoning of the workmen.

A visit to a large match-making factory is, indeed, well worth making. In them may be seen vast halls where are installed machines, miracles of mechanical ingenuity, which transform a log of wood into the finished match, completing in one operation a task that in the old days passed through eight or nine stages.

We will quote from a pamphlet issued by Messrs. Bryant and May, one of the largest firms of match manufacturers in the United Kingdom. This pamphlet, called "The Evolution of the Match," describes one of their factories as follows :—

"In one great room there are sixteen of the famous machines which cut the matches from blocks of wood, dip them in paraffin, tip them with composition, and finally pack them in boxes, entirely without assistance from the human hand. At the very start of operations a man feeds blocks of wood into the jaws of the machine, and thenceforth the mechanical monster does its own work.

Seizing the block from the man's hand, the machine grips it between rollers and forces it against rows of keen edged cutters which are so arranged that there is little or no waste. Each of these cutters (and there are usually forty-eight in a machine) severs a piece of wood of exact size and shape. At the same moment a palate rises from beneath, which thrusts these little pieces of wood into a moving cast-iron band, or rather into small holes in this band, from which the embryo matches project like bristles. This travelling band is about 700 feet in length, and follows a serpentine course in its journey, which occupies about an hour from start to finish, the speed being regulated according to the temperature so that the matches may be quite dry when they reach the boxes. When the band arrives at the finishing point, a steel oar punches out the matches stuck in its surface and they fall into the inside boxes placed ready to catch them. These boxes are kept continually shaking so that no spaces are left and the matches fill them completely. As the inside boxes fill, a steel arm presses them forward into their covers, and they are passed along a trough in dozens, quickly wrapped in paper and sealed

by a machine. Quick-fingered girls then wrap twelve of these dozen packets, and we have the gross parcels so familiar in the shops. . . . For those who enjoy statistics, we may pause at this part of the proceedings to consider some figures. The forty-eight cutters cut forty-eight matches at each stroke, and make from 150 to 230 strokes per minute—say 200. Therefore each machine cuts 9,600 matches in a minute, or 576,000 in an hour. Taking the working day at ten hours, a simple calculation shows us that the sixteen machines in this room are on a moderate estimate capable of cutting no fewer than 92,000,000 of matches in a day. But this is only one room in one of the factories. At Liverpool alone the average daily output of matches placed end to end would cover a distance of 7,000 miles. Add to this the output in London of . . . Patent safety matches, Swan Vestas, and all the different kinds of matches, and you arrive at figures which the ordinary mind quite fails to grasp."

Indeed, we read with amazement that this one firm, in a single year, can produce 90,000 millions of matches, and upwards of 100,000 miles of wax vestas and tapers—enough to girdle the earth some four times round! Every year thousands upon thousands of huge pine trees, growing tall and straight in the virgin forests of America, are cut down and turned into matches. The company is one of the largest timber merchants in the world, and in California own more than 75,000 acres of pine forests. And this is one firm alone! Equally vast firms exist in Sweden, Germany, Russia, and America.

Although phosphorus acts as a fearful and mysterious poison, yet, strange to say, it is an essential constituent of the animal body. Is it not a curious paradox that a substance so fatal to human life is so necessary for its maintenance? In the body of a normal adult man there is as much phosphorus as occurs in 800,000 of the old phosphorus matches; and since three of these matches have been known to produce death, the phosphorus obtainable from a single man could destroy or poison over a quarter of a million human beings! The phosphorus is mainly concentrated in the body as calcium phosphate, which, as we have already stated, forms the hard mineral matter of which the solid bone is built up. Large amounts also occur in the brain and nerves, and, indeed, the element is always present in the nuclei of the animal cells, whether nervous or muscular. The phosphorus atoms seem

in some way to play a very important part in the mysterious inner processes of life. They are essentially connected with the mechanisms for carrying the nervous impulses which are continually flashing through brain and nerve, and with the reproductive cells.

The phosphorus reaches the animal body from plants; and we find that all the essential parts of vegetables, especially the fruit and seeds, contain the element. To plants it passes from the soil, the great mother of all living things, which contains within it all the elements necessary for the sustenance of life. Therefore, the mere fact that phosphorus is an essential constituent of all the vital parts of living matter, whether of animal or vegetable origin, must at once teach us that phosphorus occurs in the soil; and this is so. The presence of phosphorus in the ground is an essential condition for the fruitfulness of the land. In soil devoid of phosphorus no plant can grow. Deprive rich meadow land of its combined phosphorus and it grows barren and refuses to yield as before unless the loss is replaced by manure. If phosphorus occurs in the soil, it must also occur in the running waters which pour from the land; and since these waters run into the sea, the oceans also must contain it, and it goes to nourish sea-plants. The fishes which dwell within the sea absorb it from the sea plants around them.

Since the great German chemist, Liebig, during the last century showed the importance of phosphorus for vegetation, manures rich in this element have been employed on a large and rapidly increasing scale in agriculture; and thus it will not surprise the reader to hear that ground bone dust, which consists principally of calcium phosphate, is a valuable manure, and that very large quantities of bone from the flesh extract ranches in South America are now used for this purpose, though the supply from this source is far too small to satisfy the demand. So it comes about that other phosphorus rich materials are eagerly sought and used. For many years guano was employed for the purpose. Off the coast of Peru there occur some rainless and barren islands on which millions of sea birds have dwelt for unknown thousands of years, undisturbed by man or beast, taking their

FIG. 67.—Gannets' Breeding-ground on a Guano Island.

This photograph shows a vast number of gannets breeding on a guano island. The hardened droppings of these birds, called guano, is one of the best manures extant, being very rich in nitrogen. The deposits on the Chinchas Island, off the coast of Peru—now exhausted—yielded nearly 7,000,000 tons of the substance in twenty-eight years. Besides gannets, penguins, pelicans, albatross, shags, petrels, and other sea-birds have haunted these rocky islands in their millions from time immemorial, sometimes covering the islands with guano deposits 180 feet thick.

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nourishment from the fish of the tropical seas around. In the course of ages they heaped up vast deposits of their droppings, sometimes 180 feet thick. These deposits contained no less than thirty-one per cent. of calcium phosphate, besides valuable amounts of nitrogen and other elements necessary for plant life. For a time these great guano deposits were mined on a great scale, and imported to Europe for the use of agriculturists; but within recent years the supplies have been almost completely exhausted, and so men were compelled to look about for other sources, and in our own days natural deposits of phosphate have been worked. Thus a large amount of the phosphorus manufactured in England is prepared from sombrerite, an impure calcium phosphate found in the desert island of Sombrero in the West Indies. Again, in the Spanish province of Estremadura there occur enormous masses of almost pure phosphate, termed "phosphorite," and from this most valuable manures are manufactured. In order to render such phosphates soluble and consequently more readily assimilable by plants, they are treated with sufficient sulphuric acid to convert them into the soluble monocalcium phosphate, thus:

$$\underset{\text{Tricalcium Phosphate}}{Ca_3(PO_4)_2} + \underset{\text{Sulphuric Acid}}{2H_2SO_4} = \underset{\text{Calcium Sulphate}}{2CaSO_4} + \underset{\text{Monocalcium Phosphate.}}{CaH_4(PO_4)_2}$$

Another important source of phosphorus is apatite, $3Ca_3(PO_4)_2+CaCl_2$, which often contains 5–7 per cent. of the element fluorine, and the phosphorus rich slags formed in steel making.

It had long been remarked that parts of England which were covered by beds of the geological formation known as "Lower Greensand" made admirable wheat-land. It had also been noticed that the finest hop-lands—those of Farnham and Tunbridge, for example—lay upon them, but that the fertile land was very narrow, and that vast sheets of the Lower Greensand were scarcely worth cultivation. What caused this wonderful difference in tracts of, apparently, the same sort of soil? The clue was furnished by a farmer who brought to Dr. Henslow some fossils which he had found

in these fertile tracts of land. He examined them, and found at once that they were not, as fossils usually are, calcium carbonate, but calcium phosphate. "He said at once, as by an inspiration, you have found a treasure—not a gold-mine, indeed, but a food-mine. Only find enough of them, and you will increase immensely the food-supply of England, and perhaps make her independent of foreign phosphates in case of war." His advice was acted on, and now those beds of phosphates are mined, and used extensively for manures. They are the so-called "Coprolite Beds," and are found everywhere in the Greensand underlying the chalk. Geologists tell us that they are the fossil excrements of fishes and saurians that lived, I do not know how many millions of years ago, in the Lias seas. The name is from the Greek, "kopros," dung, and "lithos," a stone. "How to explain the presence of this vast mass of animal matter in one or two thin bands right across England I know not. That the fossils have been rolled on a sea-beach is plain to those who look at them, but what caused so vast a destruction of animal life along that beach must remain one of the buried secrets of the past." *

So that, dear reader, you may have in you now atoms of phosphorus derived from wheat, which in turn obtained them from the coprolite manure with which it was nurtured, —atoms that,—just think of the wonder of it !—once formed part of fierce terrible fish and reptiles which swam in the warm seas millions and millions of years ago, and tore and fought and died along a sun-lit beach, long ages before man or beast, or even present-day England, existed at all !

Phosphorus occurs also scattered through those grand old volcanic rocks which form the greater part of the vast skeleton of the world's crust. In our chapter on silicon we gave a table of Clark's analyses of these rocks, and from this you will see that in them phosphorus, reckoned as phosphorus pentoxide (P_2O_5), occurs to the extent of 0.22 per cent. This is what makes volcanic soils so very fertile ; for volcanoes pour these rocks out in a fiery stream over the land, and

* "Half Hours Underground," p. 262.

FIG. 68.—In the Days of the Sea Monsters (Plesiosaurus and Ichthyosaurus). Some of the phosphorus atoms now in our bodies once formed part of huge reptiles, living millions upon millions of years ago, which tore and fought and died along shores vanished ages ago, before present-day England existed at all. Coprolites are the fossil excrements of these creatures.

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blast them up as ashes high into the air, which on falling sometimes cover hundreds upon hundreds of miles of land to the depth of several inches, and act as a manure, rendering the ground wonderfully fertile. Of course, when the solid lava first cools on the ground, it forms a hard barren mass; but soon the rain sets to work upon it, and with that, as by a spade, century after century, age after age, the lava stream is dug down and dispersed, atom by atom, all over the fields as rich manure. Therefore from the volcanic rocks (and if we dig deep enough we shall always come upon them) the phosphorus gets into the sedimentary rocks, and from these into the mud and broken soil which covers the hard rock, and into the plants which grow in it, and finally into the bodies of the animals which devour them. Thus Nature "can put into your veins things which were spouted up red hot by volcanoes ages and ages ago!"

And now, dear reader, I am going to let one single atom of phosphorus—and there are innumerable millions of them in every piece of bone you see, and in every box of matches—tell you its story. This phosphorus atom is, to be sure, a very tiny thing, so small that no human eye has ever seen it, so minute that a hundred million placed in a row would not cover the breadth of your little finger nail; and yet what a wonderful story this tiny scrap of phosphorus can tell of its long journey down the ages! Yes, a story wonderful beyond all measure, more wildly grand, more terrible, and more romantic than any story ever told by man. Much of its tale would be incomprehensible because it would deal with mysteries of creation beyond our ken of mind, but some parts of it would be clear to us. I can imagine it beginning its tale thus:—

"Where was I born? Ah, that I cannot tell you. It was far, far away from here, deep in the endless abyss of space, at an epoch so distant that even the earth on which you live had not been formed as yet; not even the great sun, now blazing in his glory, nor any of the innumerable multitudes of stars of the great universe now shining in the sky, had as yet come into being. No, they were mere cold whiffs of invisible vapour, scattered over all space, remnants of

worlds vanished aeons before this great universe began. Out of the vast I came, born into that great sea of Ether which stretches unbroken from star to star through all the endless depths of space. Some vast change, some murmuring and stirring of gigantic forces in its bosom, forces scarce known, scarce dreamt of, but working there in irresistible might, first brought me into being, and I hung suspended in the great void. It was utterly cold and utterly dark, and gleaming afar in the distance I could see the myriad fires of the great worlds and suns of space shining at me through the darkness. How long I hung in the void I know not. It was millions upon millions of years. Then atoms began to gather round me, streamwise, coming from afar in phosphorescing torrents, and I perceived that I already formed part of a mighty mass of gas, a huge nebula, which stretched its gigantic arms out for millions of miles, like vast flaming swords, through the darkness of space. And so I hung for aeons of ages, while atom after atom in an endless stream flashed past me in the gloom, while the great nebula slowly drew together in its glory, and began to take shape and form. Then the temperature began to rise in leaps and bounds, it grew stifling hot, and great lightnings flashed and quivered about me, and we atoms crowded more and more together, colliding, whirling, flying. Each second I smote a thousand million atoms and at each collision my motion grew more and more violent, until after millions upon millions of years of this tumult, I found myself part of an immensely hot flaming mass of gas, part of an embyro sun. There in the whirl and roar of this elemental flame I remained for unthinkable ages, but at last vast thunders beneath and around me made me aware that something tremendous was happening. It was a world—my first world—gradually condensing out of the fire mist, and the gigantic explosions which occurred from time to time were just great seas of boiling rock leaping upwards. But I will spare you the account of how I entered into that world, and saw it slowly form and develop into a fair planet, covered with wonderful swarming masses of living creatures, with great cities filled with busy life, and wonderful civilisa-

tions. Nor will I tell of how that world grew old, and passed into a vast desert, and finally, after wandering for aeons of ages in darkness and silence, burst suddenly forth into flame, the victim of a great cosmical catastrophe, and, like a bubble, vanished, exploding into incandescent gas. Nor will I tell you of how, far flung, I fell upon another world, and saw this world too in time perish; and of how I passed from world to world, and formed part of world after world, wandering in mighty migrations through space, until at last I joined the fire mist from out of which, ultimately, this present world of yours condensed amidst titanic convulsions. You will, therefore, see that even before your world began, I was old, immensely old. I will pass over all this and come to a time quite recent, merely a few hundred million years ago, when I found myself forming part of the molten fire underground. Here I lay for age after age, while the land above me was being eaten away by wind and rain and storm, and was hurried—continent after continent crumbling into ruin—into the great ocean waiting patiently to receive it. Now I was urged upwards by vast forces, slowly, steadily, for thousands of years, until finally I was uplifted to form part of a hard, cold rock, which soon reared itself into a mighty cliff, beaten upon by wind and rain and storm; I have a dim recollection of looking out from the cliff face upon a wide-spread blue sea, filled with strange vast monsters, which have long since vanished from the earth. But at last the cliff was washed away and I passed into the great body of the sea, and was absorbed into a tiny plant, living beneath the salt waters; but this was devoured by a glittering gorgeous fish, and so I entered his body. Then this fish was devoured by a reptile, which, creeping out of the water, entered a swamp and died, and its huge body decaying, I was washed into the soil, and there meeting with the rootlet of a plant, I entered into and formed part of it; and this was eaten by an animal; and so I entered into its body and formed part of his bones. While we were crossing a ravine one bright sunshiny day, millions of years ago, a green monster flashed out upon us and slew my master and devoured me. After a time my new host was

also slain in a similar manner, and his body decaying in the rank grass and vegetation of the swamp, I was ultimately washed out to sea in a sudden flood, which, coming down from the hills, swept me away. Here I mingled with the mud at the bottom of the sea, and stayed there for millions of years, and became covered over with mighty layers of mud and sand, and sank ever deeper and deeper into the earth, and at last once more felt the glow of the nether fires. Here in the great gleaming furnaces of the deep I remained for many a million of years, while miles above me the world changed and developed, mountains came and went, new and strange creatures evolved, developed, filled all the earth, and died out again. One day I was hurled forth amidst vast thunderings through the throat of a great volcano, and formed part of a molten lava stream, which in time became a fertile field covered with waving crops and golden grain. Then I entered into a grain of corn, and was devoured by a man living thousands of years ago, a mere savage you would term him, wild and fierce. From him I passed to earth once more, and since then have been passing in a ceaseless round of change through the bodies of living creatures. I have flown through the air in a bird, I have swum in the sea in a fish, I have roamed over the earth in a beast, I have formed part of innumerable plants. But the full tale would only weary you, wonderful as it is. One day, a few years ago, I was devoured by an ox while forming part of a piece of grass, and soon by the mysterious chemical forces of its body I was made to form part of its bone. The great beast was slaughtered by men, and his flesh eaten, and his bones burnt to a fine white dust in a furnace. Out of this dust I, the tiny phosphorous atom, was distilled in a furnace and found my way to a match factory, and am now in this little match-box lying on the table before you. Is my journey finished ? Oh dear no, far from it. I shall go on changing and journeying and dancing, age after age, even until the world fades away like a mist, and long after all that you see and hear around you has crumbled away and vanished into the awful maw of time. I have been taking part in the great dance of atoms which forms the basis of all passing things

and events, for millions upon millions of years, and shall continue to do so for millions and millions of years to come. I may, indeed, see this world perish, and may yet dance in worlds as yet unborn. My future will be probably even more strange than my past."

CHAPTER XV

FIRE, FLAME, AND SPECTRAL ANALYSIS

A POKER placed in a fire becomes hot, and after a time begins to emit a dull red light. As the temperature increases the light changes to yellow, and at the highest temperatures a dazzling white light is emitted. Heat, then, accompanies and produces light.* Heat is supposed to be a swift bodily motion of the molecules. When we heat a body we are merely increasing the motion of its molecules, and this increased motion becomes visible to us as light. How? Let me explain. Go out on a dark clear starry night and look up into the heavens above. Realise that you are looking into infinite space, extending upwards for ever and ever without end or beginning, in which the world flies as a dimensionless point. This vast void is not really empty. Physicists tell us it is filled with that wonderful elastic medium called the Ether, which is 2,000 million times denser than lead, and yet allows matter to pass freely through it without noticeable friction or viscosity. It is this medium which bears the light of the stars to us. The molecules are particles of matter plunged in it, accepting its motions and imparting theirs to it. When we heat a body we increase the motion of its molecules, and these, beating upon the ether, set up little tremors or waves in it in much the same way that the sudden impact of a stone with water sets up water waves. These quiverings of the ether fly through space with the velocity of 186,000 miles a second, and bursting upon the eye produce the sensation of light; but light is produced, not so much by the coarse bodily movements of the molecules as a whole, as by the very fine, enormously rapid motions going on within them. Each

* Not always. Phosphorescing bodies often emit much light but yet remain cold.

molecule, in fact, is composed of still tinier particles revolving in little orbits like planets round the sun. Still, the coarse bodily movements of the molecules, by causing molecular collisions, generate these finer movements in their internal parts, and thus it comes about that light usually accompanies heat. Hence, whenever we can by any means increase the motion of the molecules sufficiently, we shall usually succeed in obtaining light as a secondary effect. One way of increasing the motion of the molecules is to let them act chemically on each other. This is very easy to do, because we know that different sorts of atoms often attract each other with a mighty power. If, therefore, we bring different sorts of molecules close together, their atoms will rush together and combine to form new bodies. The act of rushing together and colliding produces violent motions within the tiny molecular worlds, and thus causes heat motion together with its attendant light motion. Fire is due to the intense motion of the atoms caused by the act of chemical union. For example, when coal burns in air or oxygen the carbon atoms are combining with the oxygen atoms, thus :—

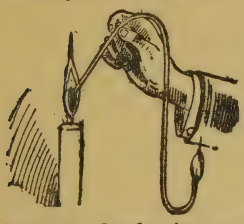

FIG. 69—Syphoning unburnt Gas from the interior of a Candle Flame.

$$\underset{\text{Carbon}}{C} + \underset{\text{Oxygen}}{O_2} = \underset{\text{Carbon Dioxide.}}{CO_2}$$

Magnify the whole process a hundred million times and we should see the burning coal as a vast surface composed of myriads of moving and rotating atoms of carbon ; while showering down upon them from all sides in a never-ending stream we should see the oxygen atoms rushing, driven towards the carbon atoms by intense attractional forces. Every oxygen atom as it reaches the carbon surface has its motion of translation destroyed by collision, and the most intense, enormously rapid, internal motions set up among the still smaller particles which build them up. These internal motions shine forth as light, while the coarse bodily movements of the molecules produce the sensation of heat.

In all sorts of combustion the case is similar. Thus the heat and light of our gas or candle flames are due to the clashing together of the oxygen of the air and the constituent molecules of our gas and candles. It is the impact of the oxygen atoms against the atoms of sulphur and phosphorus which produces the heat and flame observed when sulphur or phosphorus burn in air. It is the collisions of chlorine and antimony atoms which produce the light and heat observed when powdered antimony is thrown into chlorine gas. It is the clashing together of sulphur and copper atoms which causes the incandescence of the mass when these bodies are heated together. In short, all cases of combustion are due to the collision of atoms which have been urged together by their mutual attractions.

The reader must not imagine that this is a full explanation of the phenomenon of flame. Far from it. The most common things about us are often the most wonderful, and it excites no surprise to discover that when we study closely such an ordinary thing as a burning gas jet, we find that it has a constitution wonderful beyond all conception. The chemical changes which occur within it are of such a complex nature and succeed each other so rapidly that chemists are even now uncertain as to exactly what is going on inside it. This much, however, is certain: Within the flame we have a core

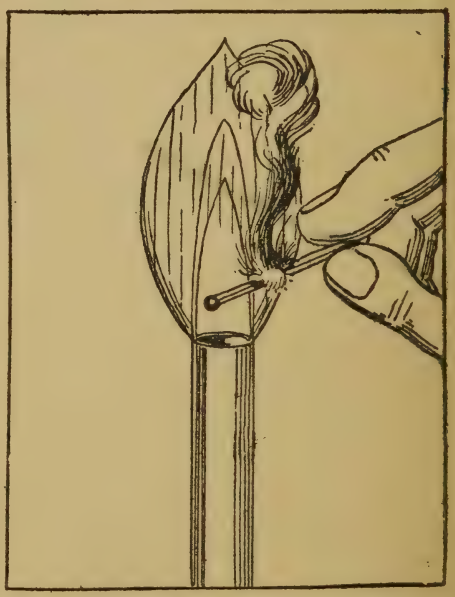

FIG. 70.—Match in a Gas Flame. Inside is a cool core of unburnt gas, into which a match may be thrust without inflaming.

of gas as yet unburnt, and outside the flame we have the oxygen of the air. The external surface of the core of the gas is in contact with the air, and here it is that the atoms clash together (and sometimes fly to pieces in so doing, shooting out a stream of electrons) and produce heat and light by their collision.

The presence of the unburnt core of gas may be shown in many ways. For example, a bent glass tube may be brought into the centre of the flame, when the unburnt gases will pass up the tube and may be lighted at the other end. Or the head of a match may be thrust quickly into the centre of the flame and held there for some time without the phosphorus catching fire, while the wood is charred and may even take fire where it is in contact with the hot external layer of gas.

Outside the internal core of unburnt gas occurs an intensely luminous layer of burning gas, and outside this again an almost non-luminous but intensely hot layer of burning gas. In this last layer the oxygen of the air unites with the hydrocarbon, burning it completely to carbon dioxide and water, thus :—

$$\underset{\text{Methane in Coal Gas}}{CH_4} + \underset{\text{Oxygen in Air}}{2O_2} = \underset{\text{Carbon Dioxide}}{CO_2} + \underset{\text{Water.}}{2H_2O}$$

Here the flame is hottest but non-luminous.

Just inside this we reach the luminous layer of gas. Here the oxygen is scanty, and the heat from the outer layers acting on the still unburnt gas within has decomposed it into innumerable solid particles of carbon or soot, which, scattered in the midst of a burning gas, are raised to a state of intense incandescence, and radiate out light copiously. Indeed, it is to these tiny particles of solid white-hot carbon that the light of our gas jets is mainly due. Very dense vapours, however, when burning, give out much light, although no carbon separates out, and some writers have considered that the luminosity of flame is due, not to the production of carbon particles at all, but to the formation of dense gaseous hydrocarbons, or to the generation of acetylene, all of which burn with an intensely luminous flame.

This may, indeed, be the case in some measure, but there can be little doubt that in a luminous flame there really do exist innumerable multitudes of particles of carbon which greatly contribute to the luminosity. This is proved by the fact that when an image of a flame standing in the track of a beam from an electric arc is cast upon a screen, the image is seen to be partially opaque in the part of the flame which is most luminous. Also when a beam of sunlight is thrown by means of a lens across a flame, two patches of light are seen on either side of the cone formed by the flame, such as would be produced by letting the solar ray fall upon a cloud of dust or smoke. Moreover, these patches of light exhibit all the polarisation effects of light scattered by a cloud of small particles.

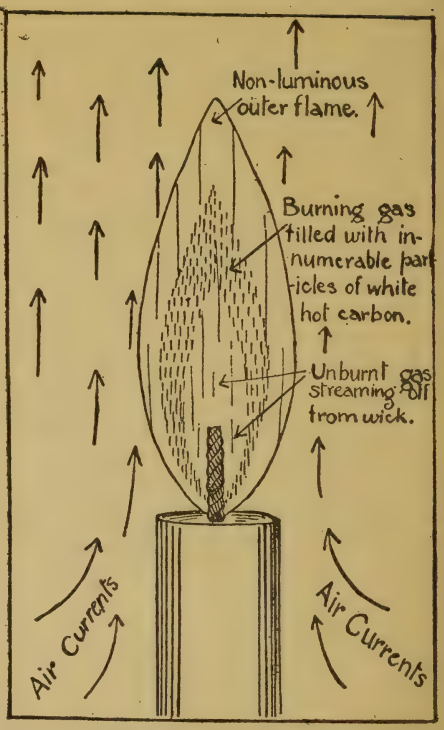

FIG. 71.—Section of a Candle Flame. On the inside occurs a layer of unburnt cool gas. Then comes a luminous layer of burning gas, and outside of all is a non-luminous layer of burning gas. The flame, small as it is, is a vast universe of colliding atoms. In the billionth part of a second there occur no less than 2,800,000,000,000,000,000 atomic collisions, each attended with its own definite incidents, and regulated by laws with a precision as great as that which guides the collision of suns in space, or swings the planets round their orbits!—so wonderfully complex is this common object!

The combustion of a candle or an oil lamp is in principle the same as that of a jet of gas. A candle is a rod of wax or

tallow, through which passes a cotton wick. When the wick burns it melts the wax at its base, and the liquid thus produced ascends the wick by capillary attraction and at the summit is converted by the heat into vapour. This vapour is a hydrocarbon like coal gas and burns like it.

We have just seen that to the existence of solid carbon particles the light of our lamps is mainly due; but the existence of these particles, in the free state, implies the absence of oxygen to seize hold of them. If at the moment of their liberation from the hydrogen with which they are at first combined, oxygen atoms were present to combine with them, the carbon particles would never separate out at all, and so we should no longer have their light. Consequently when we mix a sufficient quantity of air or oxygen with the gas issuing from a jet, so that the oxygen penetrates to its very heart, we find that the light disappears.

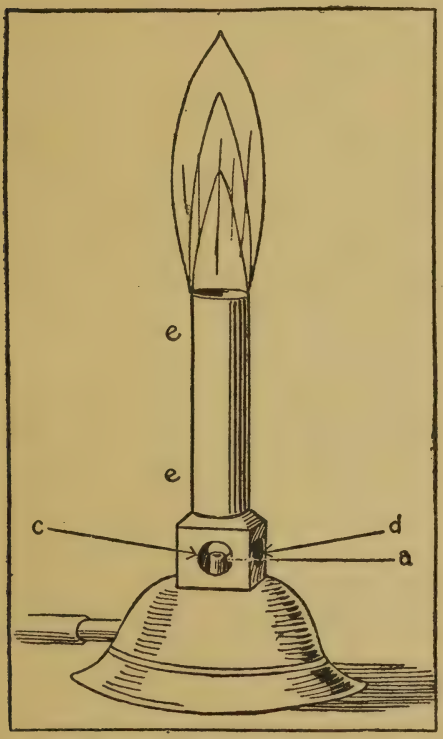

FIG. 72.—A Bunsen Burner, as used in the Laboratory. The gas streaming up through the jet *a* sucks in with it through the air-holes *c* and *d* a supply of air, which, by supplying oxygen to burn up all the carbon before it is set free, produces an intensely hot, non-luminous flame at the summit.

Bunsen's burner was invented for the express purpose of destroying by quick combustion the solid carbon particles. The gas, rushing out of a

central jet, passes unburnt up the tube (ee) and aspirates air with it through the holes (cd). The mixture of gas and air burns at the top with a pale bluish, smokeless flame. Heat is the thing here aimed at, and the almost non-luminous flame is much hotter than an ordinary flame, because the combustion is much quicker, and therefore more intense. If we stop up the holes at the base, the supply of air is at once cut off, and the flame at once becomes quite luminous. We have now a core of unburnt gas surrounded by a burning gaseous shell.

On admitting air once more the flame again becomes non-luminous. This burner is now universally used, not only in chemical laboratories, but in almost every household where a supply of gas is laid on. By its aid we obtain an intensely hot, clean flame, by means of which the chemist as well as the housewife can carry out their manifold duties. The invention of this burner, together with the invention of the gas mantle, undoubtedly saved the gas industry, which was threatened with complete ruin by the rise of electric lighting.

Nearly twenty years ago Dr. Carl von Welsbach was investigating some elements of the rare earths. He found that their oxides when heated gave out an intensely brilliant light which far exceeded that of lime-light, and it soon occurred to him that this incandescence could be increased by soaking a piece of cotton with a solution of these substances and then burning it. This was the germ of a discovery which not only saved one enormous industry from threatened ruin, but actually created another; for he found that the organic matter of the cotton burnt away and left a perfect image of its fabric, composed out of the oxides of the elements taken, which glowed in the Bunsen flame with a wonderful brilliancy and beauty. In an instant the idea of the now familiar gas mantle had occurred to him, and, being a man of action, in a short time he was actually manufacturing them in thousands.

Of all the rare elements, the oxide of the element thorium, called Thoria, ThO_2, yields most light; but strange to say, pure thoria alone gives but a feeble light. It must be mixed

with one per cent. of another rare oxide called ceria in order to bring its light-giving power to a maximum. The modern gas mantle is, therefore, composed of ninety-nine per cent. of thoria and one per cent. of ceria. Thousands of attempts since made to improve upon this composition have failed.

If you were to ask me how we are to explain the wonderful power of light emission awakened in the thoria by this trace of ceria, I am sure that I could not tell you. We are here standing on the borderland of a strange region of facts—the influence of impurity on bodies—whose exploration has, indeed, hardly yet begun; but still the fact is there and remains to this day unexplained.

A short account will now be given of how the modern gas mantles are constructed. The first mantles were made of cotton, but it was soon found that they quickly lost their light-giving power and fell to pieces. So cotton was displaced by various siliceous grasses, especially *Ramie*, or China-grass, which is now grown in very large quantities in India and Southern Italy for the purpose. The grass is first woven into "Stockings," which are then dipped into a solution of thorium and cerium nitrate. Then the stocking is carefully dried and burnt by being placed in the intensely hot flame of a pressure gas burner. The cloth disappears in a whiff of flame, and there is left behind the delicate fabric of the gas mantle. The nitrates under the action of heat become incandescent oxides, and being non-volatile preserve exactly the delicate filament of the original pattern. The mantle is then finished by dipping it into a mixture of shellac, alcohol, ether, and camphor, and allowing it to dry. This strengthens the mantle and allows it to be handled without fear of its falling into a powder, as well as giving it an inflammable coating.

Thus it was that the chance thought of a scientist, that of dipping a piece of cotton into a rare earth solution, has within the last twenty years created a vast industry in which millions of money are invested and thousands of men are employed. In Germany alone over 150 million gas mantles are manufactured every year, using up 330,000 pounds of thorium nitrate. Corresponding quantities are manufactured in

America, England, France, and Russia, and in consequence a rare mineral, thoria, previously a mere scientific curiosity in our museums, has become of immense industrial value, and is now eagerly sought for all over the world.

What is the moral of all this? It may be summed up in one word: *Research.* It was by chemical research that the discovery was made, research conducted for its own sake in a region of chemistry which no man at that time dreamt could produce anything of practical value. So it is in all branches of research. It is no accident that those nations which lead in scientific research soon lead in everything else, be it wealth, trade, war, or peace. It is, therefore, much to be regretted that in England chemical research is greatly discouraged by a miserable system of public examinations which divert the energy of our rising youth, not into discovering new facts, but into absorbing by bookwork facts already discovered by others. When, jaded by innumerable and constant examinations, the student after three years' hard work finally passes what is known as the B.Sc. examination, he at once passes into the world to earn his own living, without attempting research in any of its branches, because research does not help him either to obtain his degree or a suitable post afterwards. He is only a half-finished product. He has merely learnt to mix his colours, but has not yet learnt how to use them for painting a picture, as Mr. Challenger once put it to me. How different a system is employed for training the youth in Germany and America! In these countries chemical research pays the student in that it helps him to attain his diploma and obtain a post afterwards in which he can earn his living. He can do research while actually studying for his degree—a thing quite impossible to do in England because of the incessant examinations, intermediate and other, which are always looming on his mental horizon. The German student has to pass an examination at the end of his school course and another after three years or so when finishing his university course, but he is not troubled by intermediate examinations, and usually spends his time in mental peace, doing research work under a distinguished professor as well as studying and

attending courses of lectures to qualify for his final examination. The final result of this system is seen in the magnificent and flourishing chemical industry of that great country.

Let us now pass from this subject so painful to Englishmen, and contemplate for a short time the wonders going on before our eyes and all unheeded by us in an ordinary candle flame. Let us fasten our attention on but one aspect of it, upon the rapidity of the actions going on within it. Then, indeed, we shall excite the amazement of even the most unimaginative among us. In an ordinary candle flame there must be at the very least some 200 trillion molecules at any single instant. In the course of one short second each one of these molecules on an average makes at least 14,000 million collisions with other molecules. In other words, in a single second there occur in a small flame nearly three billion of trillions of collisions (more exactly 2.8×10^{30}, or 2.8 followed by thirty cyphers) ! That is to say, in such an inconceivably short interval of time as the millionth part of the millionth part of a second there occur no less than 2,800,000,000,000,000,000 collisions between the little atomic worlds which make up a flame !

It must be borne in mind, too, that these encounters are not mere repetitions of each other, but that each has its own definite incidents, and is regulated by laws with a precision as great as that which guides the collision of mighty suns in space, or swings the planets in their orbits. The atoms do not only collide but we now know that sometimes they actually smash and fly to pieces as the result of the collision, scattering as a confused debris the electrical particles which build them up. We know this because free electric particles are being continually shot out of a flame, and give it a power of discharging charged bodies in the neighbourhood, somewhat in the same way as radium, though of course not so intensely. Further proof of this is afforded by the fact that a flame is full of electrified particles, and can be resolved into positive and negatively charged portions by placing it in a suitable field.

The smallest candle flame is thus a vast universe of warring atoms. If all this takes place in such a tiny object in

each second, we may well ask What must be going on in an ordinary coal fire, or in a great smelting furnace, or in those vast hydrogen flames on the sun, flaring upwards for fifty thousand miles and more ? The mind reels in contemplating such numbers. The rush of events is so inconceivably vast as to escape our comprehension altogether. We have only to consider what is going on in a single candle flame in the billionth part of a second in order to obtain a dim glimpse of the inconceivable complexity and grandeur of Nature.

It seems incredible that man, an animalcule crawling upon a grain of dust flung at random into a fathomless abyss, should have succeeded in actually analysing mighty suns millions, nay billions of miles away with as much ease as he analyses a piece of rock, or a lump of salt, found to hand on the surface of the earth ; yet incredible as it seems, man has achieved this, and that by quite simple methods, too. Can the reader guess how ? Well, merely by examining the light these distant suns give forth. Each different element emits a different light, and we have only to split up the light from a distant sun into its components, in order to make certain of the presence of these elements in it.

A simple illustration will show the reader how this is possible. Let him imagine that some enormous giant lies hidden in the depths of space, and is intently watching our solar planetary system whirling round. As each planet surges backwards and forwards on its mighty path round the sun, it doubtless sets up a periodic disturbance of the ether somewhat similar to those set up in our air by a tuning fork surging backwards or forwards (disturbances which constitute sound waves). Suppose the giant could only detect the presence of the solar system by means of these immense ethereal vibrations. How would it appear to him ? He would undoubtedly sort out the disturbances in the ether into *nine* distinct sets, each set corresponding to a planet. Thus, one set of disturbances would have a vibration frequency of one year, this being the time it takes the earth to surge completely round the sun and return to its original position. Mercury would, for a similar reason, give rise to a vibration frequency

of three months, Venus to one of seven months, Mars two years, Jupiter twelve years, Saturn thirty years, Uranus ninety years, and Neptune 180 years—these being the times that the various planets take to complete their orbits around the sun.

Human beings are in very much the same position as regards the molecules of matter as this imaginary giant is in as regards the solar system. For, like the giant, a man cannot directly see the molecules. All that he can perceive are the vibrations they give forth. Each atom consists of a tiny planetary system, composed of a number of smaller electrified particles flashing round tiny orbits with the greatest regularity, much as the planets whirl round the sun. Each little particle as it goes through its tiny evolutions sets up a periodic motion in the ether which we call light. Here your conception must be perfectly clear. It is just as easy to picture an electron describing a little orbit in the atom as it is to picture the earth describing an orbit round the sun in the planetary system. The difference is mainly one of scale. The earth completes its periodic motion round the sun in the course of one year, while an electron completes its periodic motion in the atom some 400 billion times in one second. In fact, in order to produce visible light at all, the tiny electrons must flash round their orbits in the atom between 392 and 757 billion times a second. The slower vibrations produce *red* light and the faster *violet or blue* light, while intermediate rates of vibration produce intermediately coloured lights such as yellow and green. Vibrations outside these limits also exist, the longer appearing as those electrical waves used in producing wireless telegraphy, while the shorter produce chemical effects, and some people have thought Röntgen rays are composed of excessively tiny waves of this nature. But the important thing to remember is that *each particular sort of atom vibrates at its own particular rates, which are different from the rates of vibration produced by any other sort of atom.* Thus the vibrations emitted by hydrogen gas are quite different from those emitted by oxygen, nitrogen, sodium, or, in fact, by any other element. It is by this means, by identifying the light vibrations they

give forth, that chemists are able to identify elements when in regions quite inaccessible to man.

The first thing to do before going further is to explain how these different vibration rates may be rendered visible. This is done very simply. The light to be examined is passed through a glass prism—a block of glass of triangular section—and the light waves are bent from their original paths. The most rapid vibrations are bent most, and the slowest vibrations are bent least. And so the different vibrations are sorted out on a screen as fine bands or lines of differently

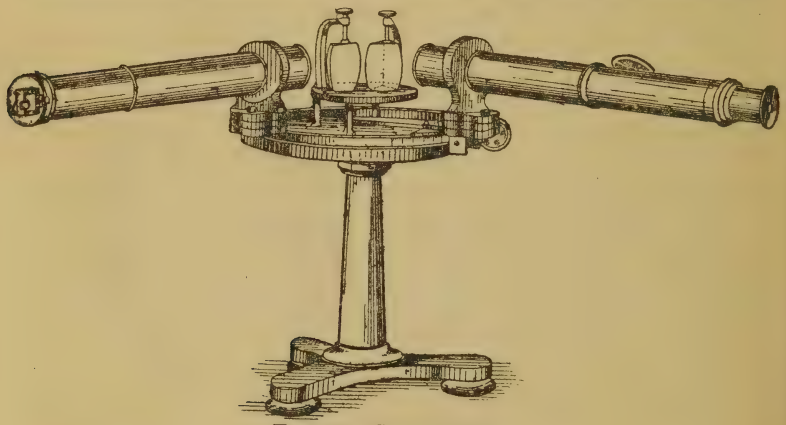

FIG. 73.—Spectroscope.

coloured light. Fig. 76 shows several of these "spectra," as the resulting images are called. Each particular band represents the vibrations of one particular electron in the atom. When we recognise the thousands upon thousands of lines which occur in the spectra of a single element, say that of iron, we recognise how complex a thing an atom must be. If, as we believe to be the case, an iron atom consists entirely of electrons, it must be built up of about 56,000 separate particles, and so there is plenty of room for complexity of vibration! An atom of mercury, for a similar reason, must consist of some 200,000 separate moving parts.

The instrument by which the light is examined is called a "spectroscope." Our illustration shows one sort (Fig. 73),

but for details the reader must consult some good works on Physics.

The more readily an atom agitates the ether when it vibrates, the more readily it accepts motion from the ether when the latter in its turn vibrates. Now it is well known that a series of slight taps may cause a considerable oscillation in a swinging body, provided only that the blows be timed to the period of swing of the body. For example, soldiers are not allowed to march in step over suspension bridges, for the simultaneous tramp, tramp, tramp, of many hundreds of feet imparts blows to the swinging bridge which, if they happen to coincide with its natural period of swing, will gradually set up such tremendous oscillations as to endanger the whole structure. Indeed, a great bridge once did break down owing to this cause, and precipitated a struggling mass of soldiers, horses, and masonry into the river below.

Now we have seen that each tiny molecule has its own special natural rates of vibration. If, therefore, we impinge on a number of similar molecules a beam of light whose vibration frequency happens to coincide with the vibration *frequency* of one of the natural periods of swing of the molecules, the ether vibrations are at once taken up or absorbed by the molecules, and they start swinging themselves. So that the ether vibrations, after passing through a layer of such molecules, are almost all absorbed, and the part of the ray coming through (if it gets through at all) is very much diminished in intensity.

If, however, the natural period of swing of the molecules does *not* happen to agree with the period of the ether vibrations, the latter passes right on, unabsorbed and undiminished by the molecules it meets with.

Now the light given off by an incandescent gas is generally composed of waves of a few definite frequencies and no others, corresponding to the definite rates of vibration of the molecules which make up the gas. If its light waves, propagated through the ether, impinge on a quantity of the same gas, the molecules of that gas will be set into vibratory motion; but that motion, being distributed over a large number of molecules, will be so weakened in amplitude as to

be imperceptible. Hence, if the yellow light emitted from incandescent sodium gas falls upon a sufficient quantity of the same gas, which is not at so high a temperature as to emit visible light, it will be almost completely absorbed. *The sodium light will not pass through the sodium gas.* By this simple fact the chemical analysis of the sun and stars is made possible. For example, the sun is a vast ball of white-hot matter. It is sending forth a mighty torrent of light of all conceivable frequencies. Among these vibrations are some which agree in period with those given out by incandescent sodium. But the sun is surrounded by an atmosphere of sodium gas, cooler than the white-hot matter below it. Hence these vibrations will not be transmitted through the sodium vapour, but will be quenched in it in the way previously explained. It is for this reason that we see in the yellow part of solar spectrum two dark lines very close together. These lines are absolutely identical in position with the pair of bright yellow sodium lines visible when glowing sodium vapour is viewed through a spectroscope. And thus we know that sodium is in the sun. In the same way, by comparing the dark lines seen in the solar and stellar spectra with the bright lines produced by incandescent gases, it has been discovered that most of the elements which occur on the earth also occur on the sun and in the stars.

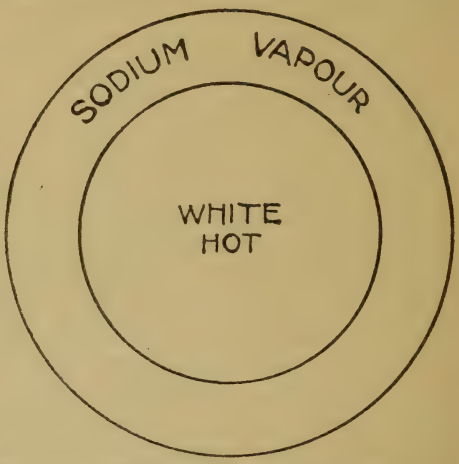

FIG. 74.—The Sun, showing how the dark sodium lines are formed in its spectrum. The dazzlingly white-hot interior sends out light of all wave lengths. Those falling upon the layer of relatively cool sodium vapour surrounding it all pass through except those which sodium vapour absorbs. And hence the sun's spectrum contains two dark bands which correspond to sodium.

FIG. 75.—The Nebula in Andromeda.

(From a photograph taken at the Yerkes Observatory.)

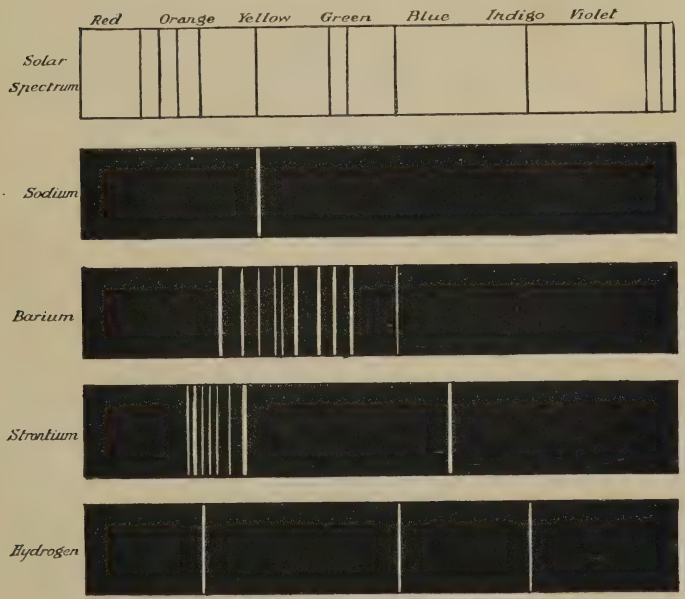

FIG. 76.—Spectra of Sun and some *heated* Metals.

The spectrum at the top is diagrammatic only, and serves to show that the sun's spectrum consists of dark lines on a coloured background. The actual solar spectrum contains an infinitely greater number of lines than are represented here.
(Illustration from Philip's " The Romance of Chemistry," p. 207. Seeley & Co., 1910.)

Face page 338.

Indeed, we have spectroscopic evidence that in the sun and in many nebulæ strange elements occur which are completely unknown upon the earth. Such elements are coronium, nebulium, asterium, and some others. Helium was in this way first discovered in the sun some years before it was found upon the table.

By noticing the displacements of the spectral lines to the left or to the right it is possible to tell the rate of motion of the stars either towards or from us. And wonderful results have thus been brought to light. Where once was thought to be rest has now been shown to be terrific motion. Many suns are rushing away from us at the rate of a million miles a day, and others are rushing towards us at an even greater speed. Vast flames of glowing gas, rushing upwards at the rate of 400 or 500 *miles a second* to the height of hundreds of thousands of miles have been shown to wheel about the sun's disc. The spectroscope has also told us of stupendous masses of glowing gas, so gigantic that the mind can scarcely grasp their extent, which lie buried in the depths of space. The spectroscope proves, also, that many of the distant stars really consist of pairs of suns revolving rapidly about each other with a period which can be exactly determined by observing the periodic changes in their spectra.

Thus the spectroscope has thrown a flood of light upon the mysteries of the depths of space, the problems of the infinitely great. But it has illuminated equally vividly the mysteries of the atomic universe, the problems of the infinitely little. For the absorption spectra of the different compounds allow us to actually measure the rates at which their molecules vibrate, and sometimes even allow us to decide the probable way that the atoms are arranged in the molecule. At the same time the fixity of the rays in the spectrum of each gas, their enormous number within the limits of the visible spectrum, and the greater number that exist beyond, show us how wonderfully regular the internal motions of the atoms and molecules are, and at the same time how extremely complex a structure these tiny objects have. The banded spectra, those beautiful lines of coloured light, introduce us to a world below the atom, and tell

us that here also, as well as in the universe of worlds and stars about us, is a theatre in which vast forces and terrific motions play their part. To the keen-eyed chemist and physicist they are "an undecyphered hieroglyphic written upon the portals of the atomic world, in which are concealed the key to some of the deepest mysteries of creation. There they extend before us, as stretched the wide Atlantic before the gaze of Columbus, mocking, taunting, and murmuring strange riddles, which no man yet has been able to solve." * Just as Columbus's long philosophic meditation led him to the fixed belief of the existence of a yet untrodden world beyond that waste of Atlantic waters, so also did these mysterious bands and lines of light lead physicists and chemists to believe in the existence of a world beneath the atom long before the discovery of radium made this a certainty. They have opened up a new world which men are only now beginning to enter and explore.

* Sir William Crookes.

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